ICT spending and inflation at the sectorial level

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ICT SPENDING AND INFLATION AT THE SECTORAL LEVEL

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Abstract

This dissertation attempts to estimate the impact of Information and Communication Technologies investment (ICT) on price setting at the sectoral level. The paper therefore fills a gap in the literature on the « new economy », which has so far focused mainly on the effect of ICT on productivity and wages. We define two possible channels: a « direct » one stemming from the decreasing cost of ICT capital, and an « indirect » coming from the productivity gains that ICT provides.

We run regressions using panel data on the evolution of prices for 24 industries in two countries: the US and the Netherlands. We estimate the direct effect by including the evolution of total costs then splitting it into prices and volumes growth rates of each factor including ICT capital. The indirect effect, on the other hand, is captured using several 5 years moving averages indicators of ICT investment and complementary investments that accompany it.

We provide, what we believe, to be fairly reliable estimations of the price effect, and find suggestive evidence for the productivity channel.

Contents

1 Introduction

In a speech to the federal board in 1996, Alan Greenspan famously described the emergence of information and communication technologies as a « once or twice in a century, at most » event. Many analysts shared Greenspan‘s interest in the extent of ICT‘s impact on the economy, particularly with respect to productivity and wages. It seems that a consensus has emerged regarding productivity gains from ICT, which started to be felt in the second part of the 90’s for some countries; however there is only suggestive evidence that ICT may have impacted wages, notably that of skilled workers.

One area that has been surprisingly left out by researchers is ICT’s effect on prices, although virtually all researchers seem to take it for granted that ICT has had a strong deflationary effect. This belief is also likely to have motivated Greenspan’s stance on monetary policy between 1995 and 2001, a period throughout which he kept interest rates low despite a booming economy; which implies that he considered that potential output was rising with current output. This dissertation, thus, intends to take one step towards the formalization and testing of the strength of this productivity effect of ICT on inflation. The paper also accounts for another channel between ICT and producers’ prices, which stems from the obvious decrease in the prices of ICT goods and services, which should have impacted the firms’ costs.

The paper is organized as follows: section 1 reviews the literature on productivity and wages in order to assess whether it is likely that ICT has had a depressing impact on labour costs. Section 2 starts with an in-depth dicussion of the two effects mentioned, before including them into a theoretical model. Section 3 presents our dataset, the variables used or created, and a discussion of some of the methodological problems faced. Section 4 will present our results focusing mainly on the performance of our « productivity » effect. Finally Section 5 provides additional robustness checks, further analysis of our « price » effect, and a discussion of the limitations of our estimations.

2 ICT,PRODUCTIVITY AND WAGES: A REVIEW OF LITERATURE

2.1 ICT and productivity

2.1.1 A global outlook

Robert Solow's famous observation that « you can see the computer age everywhere but in the productivity statistics » (1987) could somewhat simplistically be seen as the starting point of the accumulation of vast literature on the impact of ICT on the economy. The « Solow paradox » remained untill the start of the new millenium where new evidence emerged, pointing at a positive relationship between ICT spending and growth in the U.S. (Stiroh, 2002; Jorgenson, 2003). Numerous subsequent studies identified the shift in the trend of productivity around the mid-90's. Most of these studies used a growth accounting approach in which the growth of output is equated to the growth of each input weighted by its income share, plus a residual term serving which is typically interpreted as a proxy for total factor productivity (TFP). These macroeconomic studies came as a confirmation of anterior firm level studies which had already highlighted the link between ICT and productivity[1].

However this may not be as clear-cut. Gordon (2000, 2002) argues that the rise in productivity of the 90's was above all a cyclical phenomenon reflecting a favorable macroeconomic environment. On methological grounds, growth accounting is based on several implicit assumptions about the production functions such as the fact that technological change is hicks neutral, or constant returns to scale (Crafts and O'Mahon, 2001). Stiroh (2001) adds that that « the use of factor shares to proxy for output elasticities essentially assumes the results about the impact of capital » and that growth accounting disregards the large sectoral heterogeneity in production functions in a given country.

Extending the analysis to the rest of the world we find very different patterns, as shown in figure 1. Indeed, as pointed out by the OECD (2003), a significant relationship between ICT and productivity is found with « reasonable confidence » outside the US namely in Canada, New Zealand, Australia, the Nordic countries and the Netherlands excluding big ICT spenders such as the UK or Germany.

Analysts have particularly focused on the difference in impacts between the US and the EU. For instance, Bart Van ark or Luc Soete (2010) argued that the slower rate of ICT adoption and diffusion in the EU was a key element to the large differences in productivity growth observed in the last 15 years between both regions. Figure 2 provides

[1] see D. Pilat (2004) for a review of the literature on firm-level studies

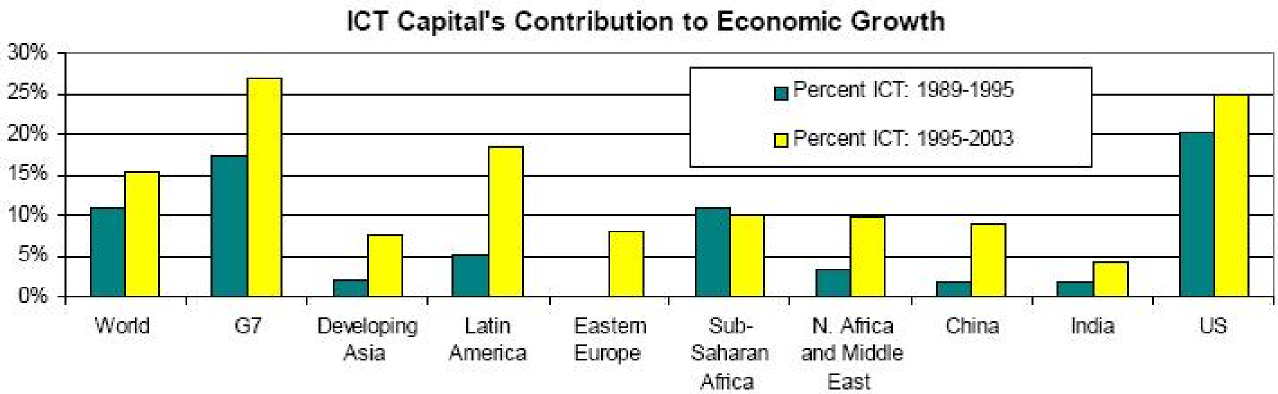

Figure 1: ICT's Contribution to Economic Growth
source: ITU adapted from Jorgenson and Vu (2005)

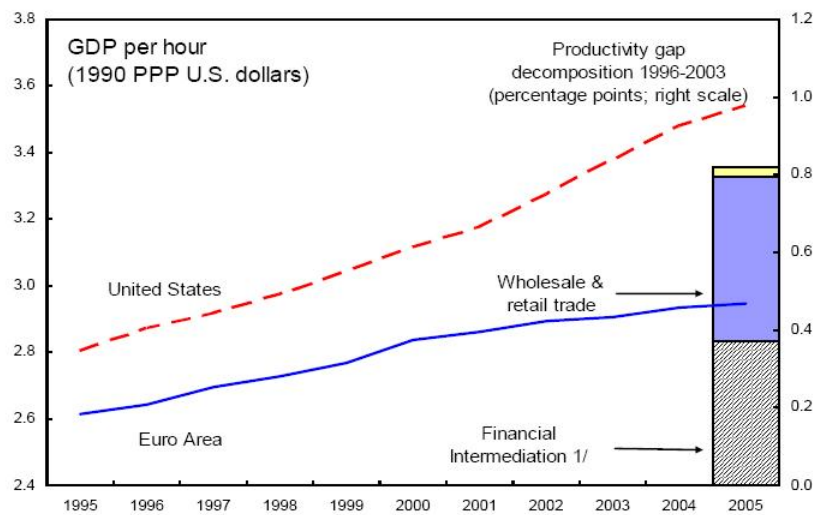

Figure 2: Wholesale and retail trade and financial intermediation explain most of the gap
Source: Groningnen Growth and Development Centre, 60-Industry Database October 2005

strong evidence in favor of this view by highlighting the preponderous part played by two very ICT-intensive sectors: wholesale and retail trade, and financial intermediation.

Europe has recently recognized its need to increase its competitiveness by becoming the most dynamic knowledge economy in the world. The Barcelona objective, in which the EU member states raise their R&D intensity and expenditures to 3% by the end of 2010 (Erasme 2006), was seen as the mean to achieve this. The above discussion implies that another way to to close this gap between the regions would be through accrued investment in ICT, and greater efforts in diffusing it quickly.

2.1.2 How can ICT foster productivity?

Why such differences? The answer to this question requires a detailed analysis of the channels through which ICT affects productivity. Maggi, Meliciani and Cardoni (2007) summarize existing works by defining three main channels of ICT usage: direct ICT production, ICT as a capital input, and ICTs as a special capital input that « generate spillovers or free benefits that exceed the direct returns to ICT capital ».

Some economists put great emphasis on this latter effect and rank ICT as a general purpose technology (GPT); that is a radical idea and/or technique that has far-reaching effects on various industries in an economy. Bresnahan and Rotenberg (1995) define three main characteristics for a GPT: firstly, they are pervasive in that they are able to be widely used as inputs in many downstream industries. Secondly, they are technologically dynamic, that is, they are able to be further improved on. Finally, they are innovation complements as they are able to increase the productivity of R&D in downstream industries.

To differentiate ICT production from ICT as an input, most studies separate their analysis between the ICT producing sector and the ICT-using one, for instance Bart van Ark, Robert Inklaar and Robert McGuckin (2002) estimate labor productivity growth for each. Their findings are summarized in table 1.

Although the ICT- producing sector has experienced very high labour productivity growth, differences in total productivity growths between the US and the EU stem primarily from the much larger ICT-using sector. This includes notably a large amount of services, since ICT is a complement to labor factor which they use intensively. In other words ICT seems more powerful as an input than as an end product.

However the evidence from such an « industry » approach on whether this is the result of « regular » capital deepening or spillovers is more scarce, as « differentiating between these forces [..] is quite difficult and subject to

	Productivity growth				GDP share	
	1990-1995		1995-2000		2000	
	EU[b]	US	EU[b]	US	EU[b]	US
Total Economy	1.9	1.1	1.4	2.5	100.0	100.0
ICT Producing Industries	6.7	8.1	8.7	10.1	5.9	7.3
ICT Producing Manufacturing	11.1	15.1	13.8	23.7	1.6	2.6
ICT Producing Services	4.4	3.1	6.5	1.8	4.3	4.7
ICT Using Industries[a]	1.7	1.5	1.6	4.7	27.0	30.6
ICT Using Manufacturing	3.1	-0.3	2.1	1.2	5.9	4.3
ICT Using Services	1.1	1.9	1.4	5.4	21.1	26.3
Non-ICT Industries	1.6	0.2	0.7	0.5	67.1	62.1
Non-ICT Manufacturing	3.8	3.0	1.5	1.4	11.9	9.3
Non-ICT Services	0.6	-0.4	0.2	0.4	44.7	43.0
Non-ICT Other	2.7	0.7	1.9	0.6	10.5	9.8
Pro memoria: with national deflators						
Total Economy	1.9	1.1	1.4	2.5		
ICT Producing Manufacturing	7.8	15.1	10.1	23.7		

a) excluding ICT producing
b) EU includes Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Sweden and the United Kingdom, which represents over 90% of EU GDP. Notes: Productivity is defined as value added per person employed

Table 1: Productivity growth and GDP shares of ICT producing, using and non-ICT industries in EU and U.S
Source: van Ark, Inklaar and McGuckin (2002, 2003a)

potentially severe measurement problems» (Stiroh 2001). The problem lies in the fact that to reap the full benefits of ICT as a GPT a firm must do more than buy new computers and softwares: it must, for example, reorganize its splitting of tasks, or undertake internal research and development to further adapt the new software to its needs. Such costs may be untangible and thus do not appear as inputs in a typical growth accounting framework.

To solve this problem some researchers like Bart van Ark and Charles Hulten (2005) have tried to proxy the extent of these externalities, mostly by trying to evaluate the « immesurable investments » that accompany ICT investments. The addition of unobservables usually has the expected effect of transferring some of the measured residual TFP to the labor factor (e.g Oliner,Sichel, Stiroh, 2007). However this approach is, by definition, subject to large measurement errors. Overall, athough there are suggestive macro econometric findings (for example Basu and Fernald claimed in 2006 that the fact that TFP rose in ICT-using sectors during the 90's is indirect evidence) the main support in favor of ICT as a GPT comes from microeconomic evidence which shows unambiguously that firms who spend more in complementary investments and organizational changes experience higher growth in productivity (Black and Lynch, 2001).

The impact of ICT as an input therefore appears to be a mix of all three factors considered above. In this context the observed difference in productivity growths between the US and Europe reflects the twice higher investment per unit of output in US, but also as pointed out by the OECD (2003) « costs and implementation barriers are related to enabling factors, e.g. linked to the availability of know-how or qualified personnel, or the scope for organisational change ».

2.2 ICT and wages

2.2.1 The wage premium between 1980 and 2000

From a neoclassical perspective we would expect wages to increase with productivity. Preliminary analysis tells us that over the period in which productivity gains were felt the most part (1995-2000), wages did take off . However this correlation could be due to many other factors, such as a positive business cycle. A more appropriate way to measure the effect of ICT on wages would be to study the wage differential between skilled and unskilled workers, or more generally wage inequality. Indeed most analysts agree that ICT may be seen as a skill-biased technical change (SBTC from here on), a view inspired from the importance of qualified personel to reap the benefits from ICT as highlighted in the previous section. Therefore we now discuss whether inequality has been rising in the US, the country that showed the greatest increase in productivity.

Early studies in the nineties seemed to confirm the role of ICT on the evolution of inequality. Katz and Murphy (1991) show that, despite a solid growth in the number of college graduates, the return to education increased during the 80's, reflecting a dramatic expansion in the demand for skilled labour[2]. Berman, Bound and Griliches (1994) first relate this trend to technological change emanating both from R&D and computer use. They find using survey, data, that both are significant contributors to the increase in the share of nonproduction workers in total cost, with a growing effect for the latter.

However in the nineties researchers found mixed results. As shown by figure 3, inequality as measured by the ratio of earnings of top decile over the bottom one stabilized. This slowdown was due mainly to a steadying or even contracting inequality between median and low earners while that between median and high earners has been rising. Thus economists agree there has been a polarization of earnings: Antonczyk, DeLeire, Fitzenberger (2010), for instance, document an increase in both demand for labour and wages for the top and bottom 20% of the wage distribution.

[2]other work on the subject include Bound and Johnson 1992; Levy and Murnane 1992; or Johnson 1997

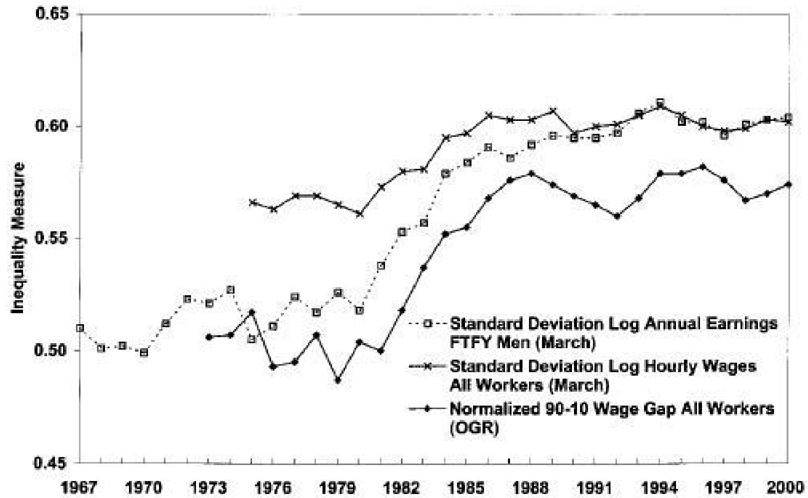

Figure 3: aggregate wage inequality
Source: Card and DiNardo (2002)

2.2.2 Discussing the real contribution of skill biased technical change

As pointed out by Card and Dinardo, « stability of aggregate wage inequality over the 1990s presents a potentially important puzzle for the SBTC hypothesis, since there were continuing advances in computer-related technology throughout the decade that were arguably as skill biased as the innovations in the early 1980s ». The SBTC also fails to explain the growing «within group » inequality which represents 55% of growth in inequality between 1973 and 1995 in the US according to Mishel and Bernstein (2003)[3].

Alternative explanations seem to do better in explaining these trends in wage inequality. Krugman (2008) puts forward the role of trade: during the 90's US imports turned to less labour-intensive goods through vertical specialization, relieving some of the downward pressure on low-skilled wages. Other authors have focused on the effect of institutional factors such as deunionisation, or most importantly the minimun wage, which has sharply decreased during the 80's. Lee's study of 1999 provides strong support in favor of this hypothesis: the introduction of minimum wage in his basic regression dramatically rises its explanative power, particularly with respect to within-group inequality, and brings all coefficients close to 0.

However technological change may still be partly explanatory. Indeed, Autor, Levy, and Murnane (2003) offer

[3]see Lemieux 2006b for a discussion of within inequality

a finer version of the SBTC in which the impact of ICT depends more on the tasks performed by workers than their skill level. In this context, during the 80's a high premium for the most qualified workers arose from the complementarity of ICT with more abstract work; while in the 90's its diffusion led to an accrued substitution of « routine tasks », usually performed by mid-skilled workers, while the demand for « manual tasks » performed by low-skilled workers remained unaltered. Autor, Katz, and Kearney (2008) discuss how this task theory compares with the minimum wage explanation, and find suggestive evidence that the latter has played a part. Similarly Michaels Natraj Van Reenen (2010) find that technology remains robust to the inclusion of trade openess on relative wages.

Additional support comes from micro level studies which have consistently found evidence of a strong ICT premium on individual wages. For instance, Goss and Phillips (2002) find that the use of the internet increases wages by over 13.5% ceteris paribus. However as noted by Goss and Phillips, it is hard to know « whether the wage premium paid to computer workers was due to more productive workers selecting jobs requiring computer usage or to the productivity enhancing power of the computer ». Thus one should be cautious of endogeneity, despite significant attempts to control for it by certain authors[4].

2.2.3 Users and producers

While the previous section suggests that the SBTC has had a limited effect on wage inequality, this may hide significant variations across sectors or individuals. Van ark et al. again dissociate the direct effects of ICT production from its diffusion on labour demand. Their findings are summarized in table 2.

As expected, IT producing sectors have experienced an above-average growth in overall wages, driven by the late half of the 90's. However the demand for labour from IT producers shrunk following the burst of the dot-com bubble in 2001. Hotchkiss et al. estimate this fall to be 16.9% (2005), but they also find that earnings still remained higher in IT. Furthermore, high-skilled workers who transitioned out of IT production saw their wages decrease but remain above the average of the industry they had joined. In a follow-up paper (2005) the same authors explain this difference by a higher premium and a higher share of directly IT-related tasks for IT producers.

For ICT-users, the productivity gains have clearly failed to translate into higher wages on aggregate, but looking in more details yields interesting insights. Van Ark et al. argue that users in services cope better than manufacturers

[4]See Goss and Phillips, 2002, or Entorf and Kramarz (1997) for a discussion of the selectivity bias and strategies to solve it

	Persons employed				Contributions to aggregate employment growth				Employment share	
	1990–1995		1995–2000		1990–1995		1995–2000		2000	
	EU(b)	US	EU(b)	US	EU(b)	US	EU(b)	US	EU(b)	US
Total economy	−0.6	1.1	0.6	2.0	−0.60	1.11	1.22	1.98	100.0	100.0
ICT-producing industries	−1.7	0.6	2.8	4.9	−0.06	0.02	0.11	0.23	3.9	4.9
ICT-producing manufacturing	−4.5	−1.6	0.4	1.5	−0.06	−0.03	0.01	0.03	1.2	1.6
ICT-producing services	0.0	2.2	3.9	6.9	0.00	0.05	0.10	0.20	2.7	3.3
ICT-using industries(a)	−0.7	0.3	1.3	1.6	−0.20	0.09	0.35	0.46	27.3	28.7
ICT-using manufacturing	−3.8	−1.6	−0.6	−0.8	−0.27	−0.09	−0.04	−0.04	6.1	4.2
ICT-using services	0.3	0.7	1.9	2.0	0.07	0.18	0.39	0.49	21.2	24.5
Non-ICT industries	−0.5	1.5	1.1	2.0	−0.33	1.00	0.76	1.30	68.8	66.4
Non-ICT manufacturing	−2.8	0.3	0.1	0.0	−0.34	0.02	0.01	0.00	11.1	6.8
Non-ICT services	1.0	1.9	1.9	2.1	0.41	0.96	0.87	1.08	45.8	50.5
Non-ICT other	−2.9	0.3	−0.9	2.5	−0.40	0.02	−0.12	0.22	11.9	9.1

Source: based on van Ark *et al.* (2002a). For country detail see Appendix table 1.
Notes: Employment is defined as number of persons employed. (a) Excluding ICT-producing. (b) EU includes Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Sweden and the United Kingdom, which represents over 85 per cent of EU employment.

Table 2: Employment growth and GDP shares of ICT producing, using and non-ICT industries in the EU and the U.S

Source: Van Ark et al. (2003)

because the gains of productivity are more labour-saving in the latter. Bresnahan et al (2002) relate labour demand to the complementary investments needed to reap all benefits from ICT, and find, using firm level data, that these investments are in fact more important in explaining labour demand for skilled workers than technical change itself. Finally Chun (2003) separates adoption and use of ICT by introducing ICT spending and the age of ICT capital in a regression on wages. He finds that both had a significant impact on relative demand of labour.

To sum up, our review of literature indicates that ICT may have been a contributing factor to the evolution of the skilled workers' wage premium. However considering the difference in trends between the 80's and 90's, and the good performance of competing explanations in the data; this contribution is not likely to be large. Across industries the aggregate performance of wages of ICT-using industries is particularly disappointing when compared to its productivity growth, despite some suggestive evidence from certain particular industries.

Crucially what we take away from this discussion is that labour productivity has been on the rise during the nineties, particularly in the second half. This increase should, in theory, have impacted more the productivity of skilled workers, but so far it seems that it has failed to significantly translate into higher wages for them. This difference between the marginal product of a factor and its reward is what drives this dissertation.

3 ICT AND INFLATION

3.1 Different channels

3.1.1 Technological change effect

Since a significant impact of ICT is hard to find on high-skilled labour, it seems safe to make this more modest claim: the evolution of overall wage level has not followed that of overall productivity. From a neo-classical point of view, this disconnection implies a departure from the economy's steady state in which each factor of production is paid his marginal product. Economists usually explain this by wage stickiness, which itself stems from workers' imperfect information or bounded rationality, and frictions on the labour market. If wages grow less than productivity, we should observe, ceteris paribus, a decrease in the firm's costs translating into lower prices.

A way to study this difference is to compare the observed rate of unemployment and the non accelerating inflation rate of unemployment (NAIRU). The NAIRU is the threshold above which an increase in the demand for labour leads to inflationary pressures. When productivity increases, this threshold should decrease as the rise in wages resulting from an increase in labour demand merely reflects a catch-up towards the « real » value of labour. Ball and Mankiw (2002) find strong evidence of this relationship, as shown in the figure 4.

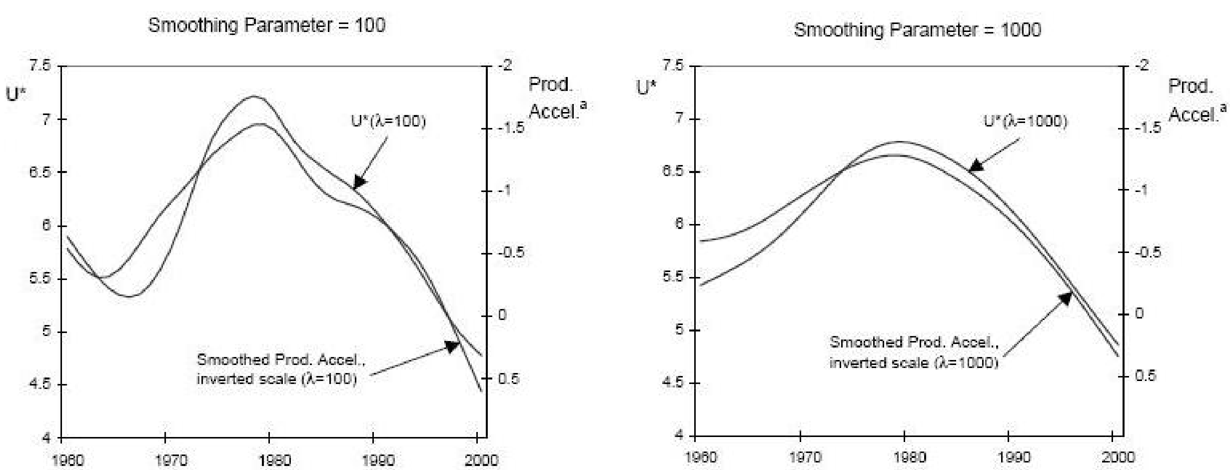

Figure 4:NAIRU and productivity growth

Source: Ball and Mankiw, 2002

When unemployment fully adjusts back to NAIRU, the postive effect of technological change on prices dies out. Inflation is thus eventually a monetary phenomenon, as suggested by Friedman (1970). However in practice this adjustment occurs after a long lag. This leads to sustained low inflation and high growth, as in the second part of the 90's. Therefore ICT may, in theory, have eased inflationary pressures through its effect on productivity.

3.1.2 ICT as a "regular" input

Following the approach of many studies on ICT and productivity, one can distinguish the effect of ICT as a special input from that of pure factor accumulation for prices. This latter effect is expected to be particularly strong as ICT inputs' prices have been spectacularly decreasing since 1980, and their share in total factor use increasing. Tables 5, extracted from our data set,confirm this intuition by comparing the two main ICT-producing sectors to the average industry in terms of prices and output growth for the US.

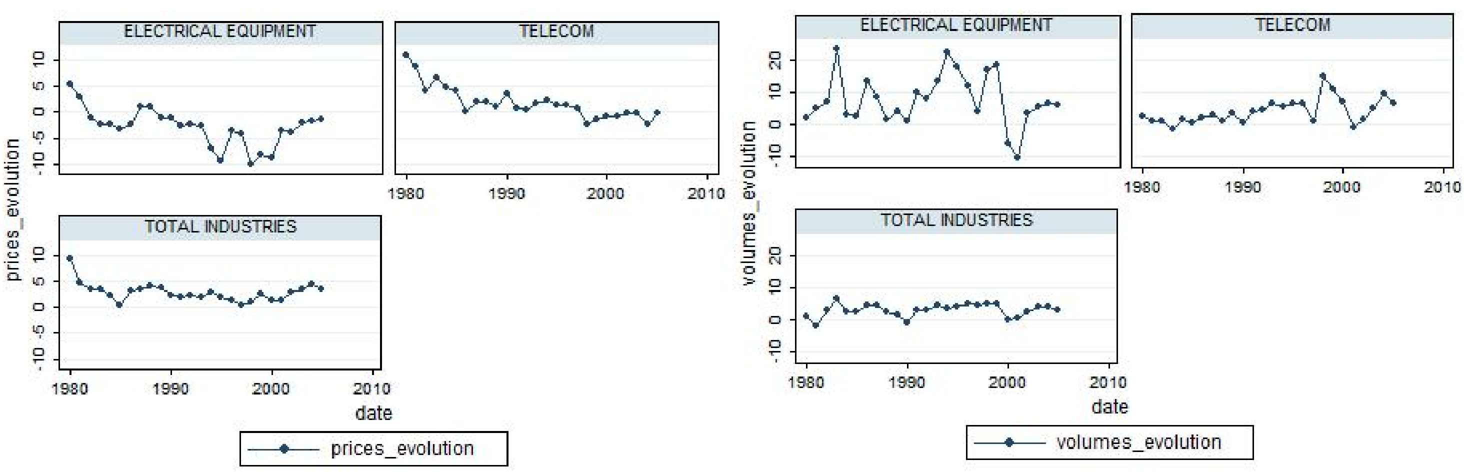

Figure 5 :ICT producing industries' volume and price evolution compared to other industries'

In the « electrical equipment » sector, this evolution was mainly driven by the falling price of computers, which has been clear to all users. Not only are computers cheaper, but their quality has also been increasing. Note that Figure 5 does adjust for this through the method of hedonic prices. Using this method the US bureau of statistics has estimated that prices of computers and peripheral equipement have decreased by a stunning 25 to 30% annually between 1995 and 1999. Therefore ICT producing sectors may well generate «sectoral disinflation »: a shock in particular sectors generates costs reductions which then diffuse throughout the economy.

3.1.3 ICT specific effects

The few authors who have been interested in ICT and prices have usually focused on different channels than this productivity one.

One branch focuses more on cost reducing externalities. In particular, ICT, and more precisely internet, should decrease the search costs both for transations among producers, and between producers. Brookes and Wahhaj (2001) investigate the effect of the latter using a general equilibrium model and find that the decline in the cost of information to producers could allow Europe and Japan to increase their growth by 0.25 point without inflationary pressures. Wadhwani (2000) adds that the shortening of supply chain and a better job seekers /vacancies matching on the labour market should help firms reduce their costs.

The « new economy » should also affect markups. Wadhwani mentions the higher competitive pressures due to more information being available to consumers; we could add direct competition from companies selling directly on the internet such as of amazon.com. However Kneller and Young (2001) argue that this effect has yet to be felt, for instance in England, books « were 22 per cent cheaper on the internet than in the High Street. But book prices generally were 3.0 per cent higher in April 2001 than they had been a year earlier, as compared to the 0.1 per cent fall in the goods component of the RPI over the same period». Another side effect of ICT is that barriers to entry to a given market may be lower.

Meijers (2006) provides a theoretical model in which cost and markup effects interact each other: « first movers » towards ICT lower their costs but increase their margin as they earn a temporary monopoly. As more firms move towards ICT this power shrinks and so does the markup. Therefore prices fall continuously untill ICT has fully diffused. Unfortunately, he does not test this.

Although we have seen that pressures on wages were quite low following the ICT boom, a final theoretical possibility is that ICT related technological progress actually pushes inflation up by generating a strong wealth effect[5]. This wealth effect could come through either actual or anticipated higher wages, or positive balance sheets effects. Inflation can also arise if a given sector experiences large productivity gains which leads to upward pressures on wages and thus higher costs for other sectors whose productivity has not risen.

3.2 Model

In order to set up a model which captures most of the above effects, we borrow the work of Romer (1986) and the comments of Barro (1998) who relates endogenous growth theories to growth accounting. In Romer's model the firm's production is defined as:

$$Y_i = AK_i^{\alpha} K^{\beta} L_i^{1-\alpha} \tag{1}$$

Where $0 < \alpha < 1$ and $\beta \geqslant 0$; and K_i, L_i are respectively the capital and labour input used by the firm i (we present a model with only two factors for clarity purposes). Kb represents the economy's worldwide stock of knowledge: when a given firm rises its own capital K_i, it rises K also. Thus production exhibits constant returns to scale if $\beta = 0$, and increasing returns if $\beta > 0$.

The firm, however, does not account for this external effect on K when deciding upon its optimal input combination ; it only considers private returns. Therefore all the derivations for optimal behavior take place in a constant returns to scale framework. Assuming in addition that the firm behaves competitively, we have:

$$Y_i = C_i = wL_i + rK_i \tag{2}$$

And factor prices equal to each factor's private marginal product:

$$r = \alpha \frac{Y_i}{K_i}$$

$$w = (1 - \alpha) \frac{Y_i}{L_i}$$

[5]see textbook « Foundations of International Macroeconomic » by Rogoff and Obstfeld for a detailed model using tradable and nontradable goods

Factor-income shares are thus given by $s_k = \alpha$and $s_l = 1 - \alpha$

This implies that, in equilibrium, the capital to labour ratios K/L should be equal amongst firms. After a little algebra [6], we obtain the following equilibrium aggregate production function:

$$Y = AK^{\alpha+\beta}L^{1-\alpha} \tag{3}$$

Differentiating this expression with respect to time we obtain:

$$\frac{\triangle Y}{Y} = \alpha\frac{\triangle K}{K} + (1-\alpha)\frac{\triangle L}{L} + \frac{\triangle A'}{A'} \tag{4}$$

Where $\frac{\triangle A'}{A'}$represents the evolution of production not explained by factor accumulation, and is defined by:

$$\frac{\triangle A'}{A'} = \beta\frac{\triangle K}{K} + \frac{\triangle A}{A} \tag{5}$$

We shall see that it is uncertain whether total factor productivity will be defined by the term $\frac{\triangle A'}{A'}$ or $\frac{\triangle A}{A}$.

Now let us apply this line of reasoning to our case. K_i now represents investment in ICT capital, and its price is now P_{ICT}. The change we apply is marginal: instead of inserting the « external » effect through an economy-wide stock of knowledge K^{β}; we introduce it within a single firm $K_i^{'b}$. K_i^{α} and $K_i^{'b}$ thus capture 2 different impacts of ICT on production, respectively the private return of ICT as an input like any other; and the impact of ICT as a special input can shift the innovation possibility fronteer in the medium run, in a way that is not yet known nor accounted for by the firm.This idea is nothing more than a reformulation of the literature led by Sherer on the importance of ICT adoption, as opposed to simple use of ICT. The firm's production function is thus:

$$Y_i = AK_i^{\alpha}K_i^{'b}L_i^{1-\alpha}$$

Differenciating we would get $\frac{\triangle Y_i}{Y_i} = \alpha\frac{\triangle K_i}{K_i} + (1-\alpha)\frac{\triangle L_i}{L_i} + \frac{\triangle A_i'}{A_i'}$, where $\frac{\triangle A_i'}{A_i'} = \beta\frac{\triangle K_i'}{K_i'} + \frac{\triangle A}{A}$. However we are interested in prices here, so that we set up a simple cost minimization problem and use a Lagrangian to obtain the following cost function:

[6]see barro (1998) for step by step derivation

$$C_i = \frac{Y_i}{A_i'}(\frac{P_{ict}^{\alpha} w^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{\alpha-1}}) \tag{6}$$

Since we assume perfect competition this yields:

$$P_i = mc_i = \frac{1}{A_i'}(\frac{P_{ict}^{\alpha} w^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{\alpha-1}}) \tag{7}$$

Where mc_i is marginal cost. Log-differentiating again we obtain our relationship of interest:

$$\frac{\triangle P_i}{P_i} = (1-\alpha)\frac{\triangle w}{w} + \underbrace{\alpha\frac{\triangle P_{ict}}{P_{ict}}}_{(a)} - \frac{\triangle A}{A} - \underbrace{\beta\frac{\triangle K_i'}{K_i'}}_{(b)} \tag{8}$$

Where (a) can be seen as representing the « direct input cost » effect, and (b) our « productivity » effect.

This model clearly contains many simplifying assumptions and its main goal is merely to convey the intuition: in practice we will be more interested in the signs than the values of the coefficients.

Let us note that the model above does not include a markup. The reason is that our estimations will not include an indepth study of the effect of ICT on markup as discussed in section 2 and 3. Indeed data on markups is notoriously hard to find ; and even if we did have such data or good proxies, isolating the effect of ICT on it would have been a daunting task, since the alleged pro-competitive effect of ICT is not necessarily a function of the industry's ICT spending. For example the book industry may not be a large ICT spender; but probably was subject to a strong competition effect from ICT diffusion. Kneller and Young agree that « at this stage there is no obvious evidence of such an effect» of ICT on markups.

4 VARIABLES PRESENTATION AND DATA ASSESSMENT

In the model above feature the two explicit effects that we are interested in: the impact on inflation of ICT as a regular input whose price is falling (or "price" effect), and that of ICT as a special input (or "productivity" effect). The goal of this section is to define how we will capture these effects in practice, and discuss the data used.

In defining some of these variables we faced a certain amount of technical difficulties. In order not to lose sight of the point of this study, we have decided to relegate the description of the way we tackled them to our appendix.

We encourage the interested reader to refer to them. Appendix B focuses on productivity proxies, C on the price effect, while D is dedicated to our controls.

4.1 Preliminary description of the sample

We use industry-level data following the classification SIC Rev3 for the US and the Netherlands, for years between 1980 and 2005. Our initial sample contains 32 industries, but only 24 for each country were eventually used in regressions[7]. The rationale for including two countries was to increase our number of observations, which was a too low in some specifications that contains only 24 sectors. The Netherlands and the US were chosen because previous studies have established that ICT had an effect on productivity for these countries, which is a necessary condition in our story. We did not include more countries partly because the data on other countries which experienced productivity gains seemed to be of lower quality, and partly due to time constraints. Therefore each observation relates to a given industry in a given country. We only use ratios over value added and relative evolutions to ensure that the sectors from both countries can be compared.

Two sources were used to constitute our dataset: EUKLEMS[8] and the STAN dataset from OECDSTAT[9]. EUKLEMS is a database financed by the European commission which provides time series on prices, volumes, and current values for output value added, and 8 different inputs including ICT capital. It also uses growth accounting to compute total factor productivity. STAN, on the other hand, provides time series data typically starting around 1987 for variables such as R&D, trade and the number of firms, which we will use as controls. We also use input-output matrices from both the OECD and EUKLEMS to construct one of our variables.

While the two classifications for Europe and US were consistent at our level of aggregation , the STAN database sometimes uses the SIC rev2 classification before 1995, while other data uses SIC rev 3. The latter contains more details than the former. For instance, and unfortunately, the three sectors of sale, retail, and wholesale trade all belong to the wider ensemble of WHOLESALE AND RETAIL TRADE in SIC rev2. In this case our only choice was generally to use the wider ensemble, which explains the loss of 8 sectors (16 in total). All our regressions have the log of producer price indice as their dependent variable.

[7]see appendix A for a list of the sectors
[8]see O'Mahony and Timmer, 2009, for a complete description
[9]the oecd.stat website provides detailed descriptions of each variable used

4.2 Measuring the ICT-productivity effect

4.2.1 ICT investment

We define ICT investment as the ratio of ICT capital on value added. A problem may be that, as the price of ICT has been falling, a firm could actually use more ICT but have a decreasing level of spending. However such a problem is likely to appear within a given sector, not across them. Indeed all sectors face comparable price reductions in their ICT equipment : the composition of ICT invesment matters little. Thus this should not affect too much our preferred regression which uses random effects. What is more, the evolution in ICT prices each year should theorically be accounted for by our direct costs measures which will capture the evolution of input prices between t and t-1. Appendix B also describes how volumes raised bigger concerns that current values.

One thing we expect of ICT as a special input is that its effect should be felt with a long lag as reaping its full benefits takes time. Bresnahan (2002) for instance estimates such a lag to be 7 years. We settle for a slightly shorter lag and use ICT over value added for the past 5 years, not including the current period t. Note that the use of lag going as far as 5 years may come as a surprise when studying a form of capital that typically depreciates quickly. We thus implicitly assume that any productivity-enhancing characteristic of an ICT product will stay available in future versions of it. We also expect the impact of ICT to be smooth as learning and that using new techniques is a gradual process. The need to smooth is felt from an empirical perspective too, as investment in ICT is quite volatile in some sectors. We thus use moving averages; so our final variable is the average of the ratio ICT investment to value added for the last 5 years prior to t.

4.2.2 Indirect investment

To account for the productive effect of ICT as fully as possible we define a measure of « indirect investment ». The idea is that as an industry becomes more productive through ICT, its services become cheaper, which should translate into lower costs for the users of the service. Therefore an industry that purchases a lot from sectors that invest a lot in ICT should have, ceteris paribus, a lower level of inflation. This idea has similarities with the work of Paul-Antoine Beretti and Gilbert Cette in 2009 who wished to measure more precisely each industry's exposure to ICT. However, the method used here differs.

The constitution of this variable was a technical challenge, and is described in details in appendix B. The idea is to compute, for each industry, the amount of ICT investment embodied in its inputs using input-output matrices in a Leontieff fashion. To do so we take ICT investment for each industry j and multiply this investment by the weight of industry j in industry i's total intermediary consumption. Note that we only go « one step » towards capturing all embodied ICT; we could reproduce the method over and over to include the level of ICT investment embodiement of industries further down the supply chain but this is unlikely to make a difference in our variable, and most importantly the economic reasoning behind it would become far fetched.

Once we obtained this « indirect ICT capital » for each industry, we take its ratio to value added and 5 years moving averages in the way as for direct investment.

4.2.3 Complementary investments

The idea of expressing ICT spending as a long lagged investment is again to account for the time needed for firms to reap the full benefits of their ICT investments. However, this time to adopt may not be equal across sectors, or vary linearly with ICT spending. As highlighted by Sherer, it will depend on complementary investments.

To account for adoption effect, we first considered using Johnson's technology matrix which uses patents citations from a sector A by sector B to proxy the technological proximity between the two[10]. We could thus have proxied the adoption rate by the proximity of each sector to ICT producing sectors. However such a matrix was only available for a given year; and we were concerned that patents in ICT production, particularly computers, may reflect inovations in components rather than new functionalities usable by others. We have also considered using a measure of unobservable investments following Sherer but this was hard to properly estimate within the time limit allowed.

We thus settled for an interaction term between the ratio of ICT investment and value added and the proportion of skilled workers hours worked in total hours. The idea is that skilled workers are the most complementary factor to ICT capital, so we expect a quicker ICT adoption when their proportion is increasing. This interation only reflects a correlation, since an increase in the number of skilled workers can be either a cause or a consequence of a high rate of adoption.

[10] see Johnson, D. K. (2002)

4.3 Measuring the ICT price effect

The direct effect of ICT as an input comes from its contribution to the reduction in the firm's total costs. To measure it, we could include the prices of inputs directly in our regression. However like in growth accounting this would lead to many problems (see again Barro, 1998). In particular assigning a constant coefficient to factor prices means assuming that the share of each factor in total cost is constant, which is to say we would be assume that there is no substitution over time. In this context, it seems more sensible to include total costs rather that individual factors in our regression, as they should be a linear function of prices. Then to identity each factor's contribution we use the mathematical decomposition from our model:

$$\frac{\triangle C}{C} = (1-\alpha)\frac{\triangle w}{w} + \alpha\frac{\triangle P_{ict}}{P_{ict}}$$

This can be estimated without econometrics using the average factor share in total costs between t-1 and t to proxy α and $(1-\alpha)$, as in growth accounting. For instance if producer prices fall by 4% following a 10% decrease in nominal costs, and the contribution of ICT to the fall in nominal cost is 50%, we conclude that the falling price of ICT has had a depressing effect of 2% on final prices.

However this mathematical derivation was obtained by solving a simple cost minimization problem for a given level of output and, since there were constant returns to scale, a given level of inputs. This is why, in the the expression above, any movement in costs comes from factor prices. In practice, costs will also vary with the volumes of factors, this effect of volumes can be accounted by using the differenced form of a more general cost function, wherein factors are allowed to vary. We also include all the inputs considered in the study.

$$\frac{\triangle C}{C} = s_l(\frac{\triangle L}{L} + \frac{\triangle w}{w}) + s_{II}(\frac{\triangle II}{II} + \frac{\triangle P_{II}}{P_{II}}) + s_{K_{ict}}(\frac{\triangle K_{ict}}{K_{ict}} + \frac{\triangle P_{K_{ict}}}{P_{K_{ict}}}) + s_{K_{nonict}}(\frac{\triangle K_{nonict}}{K_{nonict}} + \frac{\triangle P_{K_{nonict}}}{P_{K_{nonict}}}) \quad (9)$$

Where s_i is the share for each factor in total costs. This means that in our analysis we implicitly assume that volume variation and price variation will have a similar effect on prices. This assumption may lead to a downward bias in our passthrough as the impact on unit costs of variations of in factor use could be lower. Indeed factor use should increase production while price movements should not. However the impact of factor use on production will typically occur with a lag (notably for investment goods), so that it seems sensible to include volume variation between t and t-1 to stufy inflationary pressures at t. What is more, we still consider this assumption to be much more realistic than that of constant factor shares. Appendix C also discusses how this mathematical decomposition carries a small measurement error.

We express total costs in the same format as our dependent variable: we express it as an indice and take its log. This way we will be able to study how an increase of 1% in costs translates into price evolution.

4.4 Controls

There are two types of controls we are interested in: « markup» and « productivity » controls. The goal of the « markup » controls is to account for factors that directly influence price setting, in particular the strength of competition, and that of demand. We proxy the former with data on the number and the size of firms from the STAN database of the OECD. We use 2 variables: the total number of firms, and the proportion of firms with more than 200 employees to account for the fact that large firms may have monopoly power.

We proxy demand by using the price-output and output-price elasticities, computed from our EUKLEMS database, and trade data from STAN. Price elasticities are meant to evaluate the effect on demand of a decrease in price so as to have an indication of pricing power. Output price elasticity, on the other hand, should tell us whether the evolution in prices is driven more by supply or demand : if a price increase follows a rise in production this is likely to be a result of a demand shock, and conversely. An obvious problem with these two variables is that they are subject to reverse causality. To account for this, we use the change in price at t-1 and the change in value added at t for price elasticities, and the opposite for output elasticity. Finally, for our trade data, we use net trade as an indication of excess demand or supply, and the log of imports to proxy the evolution of demand.

« Productivity » controls account for variables influencing prices through the evolution of productivity. This is important in isolating the effect of our variable measuring ICT driven technological change. Two obvious candidates emerge: R&D and business cycles. The former can lead to cost-reducing process innovations, but also potentially lead to price increasing product innovations, while the second arises from the well-know observation that productivity rises when the economy is booming, possibly through increasing returns to scale.

Since R&D is comparable, in effect, to ICT in our analysis, we measure it the same way by using 5 years moving average. Business cycles are captured using the log of a 3-years moving average of indexed profits. This 3-years period was chosen somewhat arbitrarily because it provides the right balance between the length of time needed to capture a cycle and the willingness not to smooth the variable too much. Again, we take the ratio to value added to ensure all these variables are comparable with one another.

Obviously, some of these controls will impact prices through both of these channels. A positive business cycle captured through profits can, for instance, reflect strong demand and thus actually increase prices through the markup. Similarly, a large import penetration may reflect a large demand but also the fact that the domestic market is open to competition, which could drive prices down. Therefore, we should not put too much emphasis on actual coefficients on these variables. Rather, we just hope that together they control for variation from productivity and markup movements. We also add a dummy for country, 0 for the Netherlands and 1 for the US.

The downside of our controls is that they contain a large number of missing values. If we were to include all of them in our preferred regression this would shift our number of observations from 1056 observations to 107. Appendix D describe particular manipulations made to maximise our number of observations

5 ESTIMATION AND RESULTS

5.1 General approach

We decide to test equation (8) in two manners. The first is to introduce our productivity variables, which are meant to capture the productivity effect $\beta \triangle Kict/Kict$, directly in the price regression. This means running the following:

$$\log P_{it} = \underbrace{\alpha \log cost_{it}}_{(a)} + \underbrace{\beta \frac{Iict_{i,t-5;t-1}}{VA_{i,t-5;t-1}} + \gamma \frac{indirectIict_{i,t-5;t-1}}{VA_{i,t-5;t-1}} + \delta \frac{complementIict_{i,t-5;t-1}}{VA_{i,t-5;t-1}}}_{(b)} + controls_{it} + \varepsilon_{it} \quad (10)$$

We shall refer to the above as our « direct » estimation. To be sure of stripping the productivity effect of ICT, a second method would consist in instrumenting TFP with our productivity variables. This would allow us, in theory, to remove any other elements than ICT that influence total factor productivity. In this case our first stage regression would thus be:

$$\log TFP_{it} = \alpha \log cost_{it} + \beta \frac{Iict_{i,t-5;t-1}}{VA_{i,t-5;t-1}} + \gamma \frac{indirectIict_{i,t-5;t-1}}{VA_{i,t-5;t-1}} + \delta \frac{complementIict_{i,t-5;t-1}}{VA_{i,t-5;t-1}} + controls_{it} + \varepsilon_{it} \quad (11)$$

And our second stage:

$$\log P_{it} = \alpha \log cost_{it} + \log \widehat{TFP_{it}} + controls_{it} + \varepsilon_{it} \quad (12)$$

As OLS estimators behave in a satisfactory way throughout our estimations, we decide to use either fixed effect or random effects. Since industries differ largely one from the other, it seems intuitive to use fixed effects. However, here we study relative evolutions in prices and costs, not levels, so capturing time invariant factors through fixed effects does not seem justified, a priori. Nevertheless relative evolutions are not like first differences; and initial differences in the price levels may influence the way costs are passed onto prices. For instance, a firm charging high prices through a large markup may be willing to pass on a lower share of an increase in costs to prices; while a firm operating in perfect competition will not have a choice. Therefore time invariant factors may have a small impact on relative evolutions. Nevertheless we do not expect such differences to be especially correlated with ICT spending, so it may, a priori, bring noise into our estimations, but no bias. What is more, we hope our « markup » controls on demand and the strength of competition will help to mitigate this effect.

Where do we expect to find a differential effect of ICT spending? For our ICT-productivity effect we expect cross sectional variation to drive our results: an industry that has been spending more on ICT over the last 5 years should be more productive today and thus have relatively decreasing prices. Indeed within a given industry it would be hard to capture a productivity effect on prices since productivity typically « kicks in » gradually and with uncertain lags. The study of the time patterns with which productivity affects prices would thus surely require advanced time series methods, and a very long sample. Therefore, from this perspective too, random effects are preferred, and will be used in this paper.

We provide 6 variants for each approach with different combinations of controls. This reflects our willingness to include controls and to provide a full picture of all industries and consistent periods. The sixth regression provides a new Keynesian Phillips curve approach that is unrelated with the theory exposed. This regression is also, a priori, unsuited to a panel data sectoral analysis. Indeed since the goal of this paper is to observe and quantify variables that commonly affect all sectors, including each sector's own lag and forwarded inflation is not very interesting. This last regression should thus be seen foremost as a robustness check in which we study the impact of very strong variables on our variables of interest.

5.2 Results

5.2.1 "Direct" estimation

The results for this approach are summarized in table 3:

Variable	m1	m2	m3	m4	m5	m6
total_costs	.37734029	.41521595	.51467171	.35777304	.42462777	.02535722
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0853
ICT	-3.4191373	-1.2178463	-1.8539123	-.25933368	-.52881264	-.03772938
	0.0000	0.1113	0.0674	0.2797	0.1073	0.0996
indirect_ICT	.67082338	-.23775663	-.16308143	.05085726	.10499025	.00586696
	0.0232	0.5116	0.6676	0.7791	0.2463	0.3141
complement_I	.02012805	-.00298296	.01187891	-.02719667	-.01912597	-.00017102
	0.0491	0.8887	0.6871	0.0495	0.1279	0.7032
country	.0158637	.03525871	.04701411	-.00656551	-.00288792	-.00052723
	0.6843	0.5583	0.2571	0.8307	0.8489	0.4690
smallness	-3.012e-06					
	0.1192					
total_	2.750e-06					
	0.1173					
profit	-.05075894	-.06838382	.07229477	-.12662649	-.01142263	-.0011767
	0.4655	0.1332	0.1381	0.1167	0.6096	0.1488
RD	.00050316	-.24598194	-.96951028			
	0.9978	0.3017	0.0096			
elasticity~e	-.00001217	.00009096	.00013795	.00010106	.00021297	.00004255
	0.9694	0.6247	0.0815	0.2788	0.0732	0.0056
elasticity~d	.0002265	-.00063579	-.00147275	-1.586e-06	-.00001211	-2.602e-07
	0.9168	0.6321	0.0005	0.6896	0.0327	0.8622
IMPORTS	.01131217	.0124244		.00509846		
	0.0914	0.0158		0.4034		
NETTRADE	-.01113956	-.00491444		.0024126		
	0.0619	0.3403		0.7455		
NONICT				-.16552948	.15532796	-.00378088
				0.4044	0.0085	0.2413
lag_price						.48872899
						0.0000
forward_pr~e						.47829338
						0.0000
_cons	2.8176302	2.6276624	2.3254175	2.8745087	2.6177401	.03654858
	0.0000	0.0000	0.0000	0.0000	0.0000	0.3763
N	94	144	501	267	1056	1008
r2_b	.80414759	.43655521	.50442354	.19384756	.61975812	.99944838

Table 3: direct estimation results

We first observe that the variables of interest usually have the expected sign. Unsurprisingly, our variable "total cost" is our best predictor of the evolution of prices. It is between 0 and 1 as expected since firms should pass only part of their increase in direct costs to prices; and its value remains solidly anchored around 0,45 in the first 5 regressions. Note, however, the inclusion of lagged and future price evolution strongly affects its coefficient. However, as mentioned, we do not see this specification as economically instructive, so that we only observe here that the log of costs remain significant at the 0.1 level.

With respect to our ICT/productivity variables, our 5 years moving averages of ICT investment over value added are positive and significant in half of the specifications and borderline significant in two others, including the new Keynesian form, which we see as a good sign of robustness. The coefficient should be read as semi elasticities: for instance using specification (5) an increase of 0.1 (say from 10% to 20%) in ICT's share in value added over the last 5 years should lead to a decrease in inflation differential of 5.29%, which is broadly consistent with previous findings on the effect of productivity over costs (such as Prado, 2008). However these coefficients also vary strongly from -0.25 to -3.51, in the first 5 specifications, so our effect, although it seems existent, remains hard to evaluate.

The results for indirect investment are insignificant, and positive in our preferred regression (5). This finding is a bit disappointing, but trying to capture an indirect productivity effect on such a complex process as pricing decision was quite ambitious. We considered the possibility that this variable is collinear with direct ICT investment, however it does not appear to be. More interesting is our measure of complementary investment which is of the expected sign with lower p-values as our sample size expands. However we note that the variable gains significance when R&D is left out, which tells us that the significant of this interaction may come more from the share of skilled workers' evolution , which may be related to R&D, than ICT.

Nevertheless considering these variables together we regard the performance of our productivity measure as quite satisfying. To check this we add all of these 3 variables to constitute an index: it is negative and significant at the 0.1 significance level in all regressions except the first one.

Turning to our markup controls, we find, as expected, that the log of import is our best performing variable, with a positive sign and significant in two out of the three regressions in which it features. Net trade is much less robust however. Looking at the dummy for countries we find it to be consistently and strongly insignificant in all specifications. This finding is reassuring as it implies that the fact that we used two different countries has not impacted on our results. « Total » and « Smallness », which stand for total number of firms and the proportion of small ones, obtain poor results. For the former this could reflect the fact that although bigger firms may have monopoly power, they could also exhibit increasing returns to scale, which would drive prices down. As these variables are costly in terms of observations we drop them in all remaining specifications. The picture is mixed for our two elasticities: price elasticity of production has the expected sign and is usually significant, but the converse is true for the output elasticity of price.

Finally we discuss our productivity controls. We find as expected that profits of the last three years have a negative impact in all but 1 specification, albeit not significant. As mentioned, profits are potentially subject to an omitted variable problem since they could be driven by demand and thus have a positive effect on price. So, the fact that it is negative may mean we have captured well productivity effects. Interestingly we find that profits are indeed closer to significance when the log of imports, our best proxy for demand, is included. With respect to R&D we see that although it is positive in (1), which is not to be trusted, it becomes negative then significant as the sample size increases. R&D is nevertheless problematic as its inclusion biases our sample towards manufacturing goods, as there is very little data on R&D for services. We have thus decided to include non ICT investment which can be found in EUKLEMS when R&D is left out. Its results are mixed, notably in our preferred regression (5), in which it is positive and significant. However since R&D has in theory two opposing effects on inflation depending on whether it is dedicated to process or product innovation, the fact that we do not obtain clear-cut results for non-ICT investment may not mean it is a bad proxy.

All the above regressions are corrected for heteroskedasticity, as initially our Breush and Pagan tests rejected the null of no heteroskedasticity for all the specifications involved. We also ran these regressions controlling for autocorrelation in the error term and actually obtained marginally better results. The interested reader may find these results in appendix E.

5.2.2 Instrumental variable estimation

Table 4 summarizes the results.

Variable	m1	m2	m3	m4	m5	m6
log_TFP	-1.1555135	.15131784	-.36994017	-.66468731	-1.1113774	.09636027
	0.0129	0.1952	0.0016	0.0009	0.0000	0.1647
total_costs	.52946902	.37226479	.60101144	.42568307	.57630516	-.02680145
	0.0000	0.0000	0.0000	0.0000	0.0000	0.4534
country	-.10759263	-.01370554	.01630127	-.06685651	-.03526699	.00183487
	0.2198	0.8159	0.6532	0.0856	0.1935	0.5485
smallness	-9.058e-06					
	0.4007					
total_	8.205e-06					
	0.3987					
profit	-.11463778	-.0795122	.01772566	-.08422716	-.06735891	.00107631
	0.2277	0.1039	0.5081	0.0600	0.0003	0.5824
RD	.56622446	-.100888	-.71629988			
	0.1605	0.6732	0.0026			
elasticity~e	.00016628	-.00002564	-.00004718	-.00002006	-.00004083	3.300e-06
	0.4476	0.8322	0.5500	0.8996	0.7464	0.9229
elasticity~d	.00498681	-.00074829	-.00161236	-.00001701	-.00003044	1.306e-06
	0.2105	0.6541	0.0000	0.1930	0.2787	0.8620
IMPORTS	-.01849342	.00899109		-.00261781		
	0.2233	0.1582		0.6444		
NETTRADE	.02143747	.00022038		.01048007		
	0.0860	0.9691		0.0178		
NONICT				-.01041779	.26126845	-.01040805
				0.9257	0.0001	0.1880
lag_price						.56242687
						0.0000
forward_pr~e						.50804935
						0.0000
_cons	7.4194506	2.0053643	3.5112126	5.5945349	6.9926977	-.64141353
	0.0000	0.0000	0.0000	0.0000	0.0000	0.1864
N	78	144	501	267	1056	1008
r2_b	.85783155	.01805659	.41043619	.45168758	.63096238	.99601482

legend: b/p

Table 4: instrumental variable approach

These results are very similar to those obtained previously, and the same comments apply. Thus one would be tempted to conclude that this table provides additional support to our story. However the first stage of our instrumental variable estimation provides very puzzling results. Table 5 gives the results this first stage for (5), but the patterns observed remain across specifications:

First-stage G2SLS regression

Number of obs	=	1056
Wald chi(9)	=	151
Prob > chi2	=	0.0000

log_TFP	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
total_costs	.1379285	.0178364	7.73	0.000	.1029698	.1728871
country	-.0434536	.032632	-1.33	0.183	-.1074113	.020504
profit	-.0084176	.0212548	-0.40	0.692	-.0500764	.0332411
NONICT	.1149076	.0714075	1.61	0.108	-.0250486	.2548638
elasticity~e	.0000996	.0001426	0.70	0.485	-.0001799	.000379
elasticity~d	-.000019	.0000317	-0.60	0.550	-.000081	.0000431
ICT	-.4130698	.3810928	-1.08	0.278	-1.159998	.3338584
indirect_ICT	-.2046675	.0726928	-2.82	0.005	-.3471429	-.0621922
complement_I	.0479674	.0132239	3.63	0.000	.0220489	.0738858
_cons	3.975101	.0852192	46.65	0.000	3.808074	4.142127

Table 5: first stage results for regression (5)

This implies that ICT variables are, at best, poor instruments; and at worst significantly negatively correlated to TFP. What is more, non ICT investment does seem to have the expected positive sign, which implies that ICT investment is both individually and relatively harmful to total factor productivity.

5.2.3 An apparent puzzle

The previous section's results leave us with this puzzle: although ICT spending and TFP have comparable effects on prices setting, both are negatively correlated one with another. There are two possibilities to explain such a pattern: either our direct regression captures an effect of ICT on inflation that does not go through productivity, or instrumenting TFP is not the appropriate way to capture the productivity effect of ICT.

These two competing explanations are related to an old debate of growth accounting on how much TFP can be trusted, and what it exactly captures. Solow initially viewed as it a measure of technological change, but very soon authors such as Griliches and Jorgenson questioned its relevance by discussing its several sources of biasness (1967). One particular source of concern is summarized by Prado (2008) in these terms: « To view TFP as an expression of technical change suffers [...] from the fact that the capital stock is an intrinsic carrier of new technology. New technology is embodied in the capital stock. Without technical change, capital accumulation would just amount to piling capital goods of already existing technology, and diminishing returns would thwart further efforts to raise output. ». Before carrying on we should also note that this problem is not necessarily incoherent with the discussion of section 1 on ICT and productivity, since these studies usually consider the effect of ICT on labour productivity, not TFP.

The issue of whether capital inputs account for technical change in growth accounting can be expressed mathematically from our model of section 2. Going back to Romer's production function (1), if growth accounting only captures the private returns of ICT, that is, its effect as a « regular input », then TFP evolution should be equal to A'in equation (5), that is:

$$\frac{\triangle A'}{A'} = \frac{\triangle Y}{Y} - \alpha\frac{\triangle K}{K} - (1-\alpha)\frac{\triangle L}{L} = \beta\frac{\triangle K}{K} + \frac{\triangle A}{A} \tag{13}$$

On the other hand, if growth accounting does account for social returns, which is to say the effect of ICT both as a regular and a special input, then the actual obtained TFP would be only A not A', so that:

$$\frac{\triangle A}{A} = \frac{\triangle Y}{Y} - \alpha\frac{\triangle K}{K} - (1-\alpha)\frac{\triangle L}{L} - \beta\frac{\triangle K}{K} \tag{14}$$

The key difference is that in (13) TFP and K (ICT as a special input in our analysis) are positively correlated, but in (14) they are negatively correlated. In other words TFP is defined by (14) then the negative relationship observed between our measure of TFP and lagged ICT investments is not puzzling. This would just imply that this IV estimation was not appropriate.

On the other hand if TFP is in fact defined by (13) then the results the first stage of our IV estimation are a real puzzle. We should therefore conclude that the productivity effect is non-existent, since there appears to be no link between ICT and TFP. With respect to our direct estimation this would mean that our 5 years moving averages indicators of ICT investments probably only represent the capital deepening effect of ICT on inflation. The negative coefficients on inflation would thus reflect either a spurious relationship, or the fact that ICT services became cheaper over time.

In this context, the question of the measurement of capital stock becomes crucial. EUKLEMS uses a perpetual inventory method with geometric depreciation and expost rates of returns[11]. Biatour et al. (2007) find that this method of estimating capital volumes, usually gives higher contribution of TFP to growth than others. Although

[11]see Timmer and O'mahony (2009) for more details

the difference is very marginal, from this perspective EUKLEMS should give us a slightly higher correlation between lagged ICT investment and TFP. Another element in EUKLEMS may play against us however: the use of US hedonic prices. Indeed, EUKLEMS uses the US quality adjusted deflators for the US, and applies Schreyer's harmonisation procedure (2002), which is also based on the American deflators, to other countries. Since the US correction is the strongest of all national bureaus this could mean that the ICT capital stock growth is relatively higher in EUKLEMS, and thus an undershooting of TFP. Overall it is hard to judge whether the problem is more acute in our dataset.

5.3 Who to trust? An investigation based on 3 robustness checks

While we do not expect to disentangle capital accumulation and TFP, thus settling a 55 year old debate, in this dissertation[12], we may provide a few elements to help us discuss which of our two estimation strategies is the most appropriate. From the discussion above we can expect three patterns:

1) If our lagged ICT measure captures simply a capital accumulation effect in the direct estimation, the inclusion of lagged cost evolution should take on some of the variation previously explained by our productivity measure, as it should account for part of the price effect at t-2.

2) In the same vein, a productivity effect should be felt with a longer lag than pure accumulation effects. Therefore if we change our measure of ICT to put more weight on the more distant lags of our 5 years ICT investments measures, we should isolate the productivity effect. Thus if the variable remains significant, it would imply that our ICT variables in our "direct" estimation do not measure only accumulation.

3) Finally if TFP is biased by the inclusion of ICT in growth accounting, using only capital without differencing between ICT and non ICT should increase the correlation between TFP and ICT capital. Indeed including solely capital is a way to isolate pure accumulation effects by considering any unit of capital should have the same impact on production. If this modification in the way TFP is measured does not affect the negative relationship between ICT and TFP found in our IV regression, it would imply this a relationship was more than a statistical phenomenon.

Implementing this in our regression should provide us with robustness checks to judge each possible estimation strategy. 1) and 2) are tests of whether our direct estimation ICT measure capture productivity, while 3) is more a test of whether TFP already accounts for the productivity effect of ICT. All the results for these three checks can

[12] Abramovitz first described TFP as « a measure of our ignorance » in 1956

be found in appendix F, G, and H, for 1) 2) and 3) respectively.

In testing 1) we simply add the lag of the log of total costs in our direct regression. This inclusion does not affect our results: if anything, our productivity measures gain in strength and significance. ICT/VA is significant in all but one regression, and the two others are usually negative and in some cases significant.

To test 2) we need to attribute weights to each lag of ICT/VA, which is to say, to specify a form for the learning curve of ICT capital. We pick a traditional form in which costs reduction is an increasing and concave function of time. $y = x^{0.5}$. Each lag is thus multiplied by the squared root of its distance to t in years. We apply the same transformation to our indirect investment measure. Again the results are marginally better, the p-values of ICT/VA decrease further: the variable is now significant at the 0.01 significance level in 4 out of 6 forms, the two others productivity measures obtain, as usual, less clear-cut results.

Finally testing 3) required that we compute our own TFP. We include 3 factors: Labour, intermediary consumption, and capital. This is a rough measure compared to EUKLEMS' TFP series which include 8 factors; but the goal here is simply to run a robustness check. In the case of capital, the grouping of two types of investment is, as mentioned, deliberate. Appendix E shows the result of the first stage regression of our IV estimation for our preferred specification (5). It appears that our productivity measures switch signs and now covaries positively with TFP, and significantly so, for our complementary investments measure. Non ICT investment, on the other hand, loses significance.

Therefore all of our three checks seem to point to our direct estimation as the most suited one to capture a productivity effect. 1) and 2) show that the results of section 4.2.1 were not, a priori, driven by the fact that ICT/VA captured a short run effect of factor price decrease on costs, while 3) tells us that the relationship between ICT and TFP is indeed affected by the fact ICT accumulation is used to compute TFP.

In conclusion, although our instrumental variable approach casts doubt over the causality of the correlation between ICT and prices, the relevance of our first estimation strategy seems greater. Therefore we continue to view our results as suggestive, albeit not conclusive, that ICT has indeed diminished real costs and thus prices by increasing productivity.

6 LIMITS, FURTHER ANALYSIS, AND POSSIBLE EXTENSIONS

This section is split into 3 quite distinct subsections; we first go deeper into the analysis of our productivity effect. We then provide a more in depth analysis of our price effect, trying to estimate how falling ICT prices have affected costs using Leontieff economics. Finally we attempt to discuss possible limitations and strengths of our estimation.

6.1 Productivity effect: who and when?

6.1.1 Who?

We distinguish between users and producers in order to have an indication of how much our results are explained by the ICT producing sectors. Indeed as these sectors exhibit high ICT spending and rapidly decreasing prices they probably contributed to our results. Table 6 shows the results of a similar regression that that of section 4.2, but excluding « ELECTRICAL AND OPTICAL EQUIPMENT » and « POST AND TELECOMMUNICATIONS ».

Variable	m1	m2	m3	m4	m5	m6
total_costs	.40726742	.42190434	.55287232	.41439946	.48602348	.05790983
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0108
ICT	-2.2917806	1.3918232	-1.7169159	.35875345	-1.3428189	-.11692885
	0.0002	0.3628	0.1668	0.7359	0.0175	0.0242
indirect_ICT	.5367329	-.00589395	.17966434	.0788177	.20177753	.01894175
	0.0385	0.9863	0.4578	0.8096	0.0024	0.0144
complement_I	-.01525562	-.04964723	.03071252	-.0214824	.01556039	.00001341
	0.2603	0.1585	0.3329	0.4423	0.4021	0.9903
country	.0567255	-.01697982	.00668233	-.0193415	-.02588349	-.00155099
	0.0106	0.6242	0.7909	0.3993	0.0919	0.1488
smallness	4.245e-06					
	0.0130					
total_	-3.852e-06					
	0.0115					
profit	-.0704201	-.07399317	.06061162	-.03404534	-.00340654	-.00059912
	0.0106	0.0615	0.1632	0.3984	0.8444	0.7142
RD	.0629778	-.56745029	-1.0257307			
	0.7362	0.3683	0.0650			
elasticity~e	-.00084362	.0002496	.00002354	.00001792	.00004972	.0000448
	0.3653	0.4609	0.7725	0.7840	0.5514	0.0171
elasticity~d	.00155328	-.00030297	-.00141056	-4.602e-06	-.00001701	-1.519e-06
	0.2141	0.8208	0.0009	0.0877	0.0008	0.4363
IMPORTS	.01065186	.00330733		.00246347		
	0.1712	0.5862		0.5526		
NETTRADE	-.00776326	.00047939		-.00310042		
	0.2767	0.9408		0.4739		
NONICT				.02630537	.20684566	.00719725
				0.6862	0.0025	0.1691
lag_price						.45665915
						0.0000
forward_pr~e						.45063705
						0.0000
_cons	2.6179428	2.5950188	2.074169	2.6843344	2.3180861	.15886142
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
N	84	130	459	249	968	924
r2_b	.9592101	.75335985	.62677306	.7728675	.71742579	.99838594

Table 6:direct estimation excluding ICT producing industries

The coefficient on our most efficient variable « ICT » from section 4 are only negative in 4 out of 6 specifications. However the p-values are much lower when the coefficient is negative, and the variable is actually significant at the 0.05 level for three of our specifications, including our preferred one (5), and (6). Indirect investment also confirms that it may have a counterintuitive coefficient as it is positive and significant in (5) and (6). However the effect itself is much more modest than that of ICT.

Overall this table suggests that ICT producing industries have partly, but not fully, driven our results.

6.1.2 When?

We now look at the time patterns of our results to see when the deflationary pressures from ICT were felt the most. This table could also be seen as a robustness check since, as mentioned in section 1.1, the productivity gains in the US and the Netherlands were only felt in the data from 1995 on; and especially between 1995 and 2001. We thus expect our results to be more significant in this period. Table 7 hows the results from our preferred regression (5) for 4 5-years period between 85 and 2005:

The coefficient on our « ICT » variable is indeed higher between 1995 and 2000. Its value -0.72 implies that an increase of 0.1 in the ratio of ICT over VA would lead to a decrease of 7.2% in prices. The next period also performs well with a slightly lower coefficient but also significant at the 0.01 level. The two previous periods show no significance, although the sign is as expected. This is in accordance with previous work. The coefficient on indirect ICT spending is significant and negative in the last regression. It would be tempting to see this evolution as a sign that the productivity effect starts spreading onto the economy, but considering the performance of our indirect investment variable, this would be quite a long shot.

Variable	m86_90	m91_95	m96_2000	m2001_2005
total_costs	.44518809	.371154	.37808475	.67952781
	0.0000	0.0000	0.0019	0.0000
ICT	-.46306977	-.17886272	-.72281993	-.64785404
	0.1816	0.4030	0.0004	0.0979
indirect_ICT	.20382391	.10330333	-.095226	-.75433802
	0.0001	0.4082	0.6476	0.0124
complement_I	.01107638	.005873	.00256109	-.0201431
	0.4094	0.4109	0.7590	0.1196
country	-.04065244	-.00271124	.00223012	.12224774
	0.1209	0.8073	0.8463	0.0299
profit	-.02067755	.00268245	.0144609	.09220425
	0.3492	0.8421	0.6067	0.0380
NONICT	.00097067	-.03506315	.09657552	.18097498
	0.9900	0.2797	0.0120	0.0823
elasticity~e	-.00006126	.00006759	6.458e-07	-.00007277
	0.4798	0.1617	0.9963	0.1042
elasticity~d	-.00014014	8.367e-06	-.00092572	-.00025907
	0.0410	0.0013	0.5532	0.2130
_cons	2.5587323	2.8972386	2.8618864	1.4938228
	0.0000	0.0000	0.0000	0.0000
N	240	240	240	240
r2_b	.36007445	.25918388	.31529686	.50682147

=	1056
=	151
=	0.0000
f. Interval]	
	.1728871
	.020504
	.0332411
	.2548638
	.000379
	.0000431
	.3338584
	-.0621922
	.0738858
	4.142127

Table 7: results for specification (5) per 5-years period

6.2 Estimating the price effect

Applying the method described in section 3.3, we now separate the cost variation into the volume and price contributions of each of our 4 factors. In face of the extension we will later include, it is preferable to focus on only one country. We pick the US because its data seems marginally better. However for the Netherlands the contributions have a similar pattern as those for the US as summarized in the figure 6, in which the total cost variation is normalized to 100%, and contributions averaged over 5 years periods across industries:

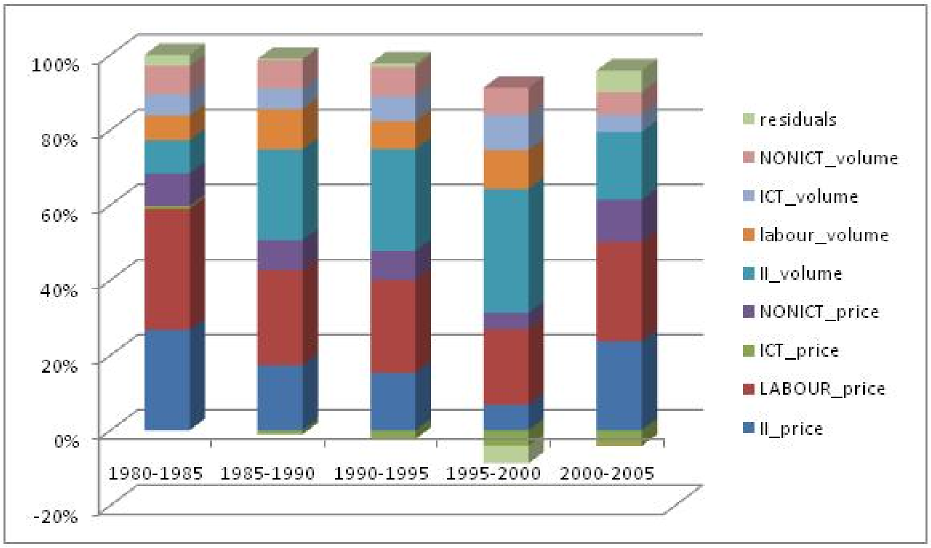

Figure 6: Contributions to total costs evolution, in %

The contribution of ICT is bounded by its fairly modest share in total cost. Nevertheless ICT has played a part: the large volume increase contributed positively to costs, and the falling prices contributed negatively.

In values the price contribution in % points compared to the evolution of total costs for the whole economy is:

	total_costs_g	ICT_price
1980-1985	6.964743	.0511106
1985-1990	6.324152	-.0709065
1990-1995	4.982533	-.1198421
1995-2000	6.223819	-.3083382
2000-2005	4.967278	-.2116257

To translate this contribution into a price effect we need to multiply it by the pass-through from costs to price, which is evaluated by the coefficient of costs in our regressions. We use the value of our preferred regression (5) from our direct estimation: 0.424662777. We should note that using the estimated pass-through brings with it its share of potential biases and measurement error; so the following figures should be considered with care:

1980-1985	0,02170477
1985-1990	-0,03011135
1990-1995	-0,05089248
1995-2000	-0,13093976
2000-2005	-0,08986956

These figures should be seen as an indication of deflationary pressure from ICT prices, as they are equal to the difference between what costs are and what they would have been if ICT prices stayed constant. We see here that this effect is non negligible, especially during the 1995 to 2000 period where inflation was 0.13% lower thanks to ICT.

However to take into account the full effect of ICT in each industry i we should not only consider the direct effect from ICT spending, but also that on other industries' prices, which feed back into i's costs through intermediary consumption. To express this mathematically we use the decomposition of equation (9), we also continue defining the downward pressures on costs as the difference between what costs are and what they would be without the decrease in ICT prices; so that any other term than $P_{K_{ict}}$ and P_{II} vanishes. We obtain the total pressure on costs for a given industry D_i, as a function of ICT price variation $\frac{\triangle P_{K_{ict}}}{P_{K_{ict}}}$ weighted by its share in total cost $s_{K_{ict_i}}$.

$$D_i = s_{K_{ict_i}} \frac{\triangle P_{K_{ict}}}{P_{K_{ict}}} + 0.425 s_{II} \begin{pmatrix} \tau_{i1} & ... & \tau_{in} \end{pmatrix} \begin{pmatrix} D_i & .. & D_n \end{pmatrix}^{\mathsf{T}}$$

Where τ_{ij} represents the share of industry j in i's intermediate consumption. Defining the contribution of ICT to the decrease in cost as $d_i = s_{K_{ict_n}} \frac{\triangle P_{K_{ict}}}{P_{K_{ict}}}$, and extending to all industries, we get:

$$\begin{pmatrix} D_i \\ .. \\ .. \\ D_n \end{pmatrix} = \begin{pmatrix} d_i \\ .. \\ .. \\ d_n \end{pmatrix} + \underbrace{\begin{pmatrix} 0.425 s_{II_I} \\ . \\ . \\ 0.425 s_{II_n} \end{pmatrix} \left(\underbrace{\begin{matrix} \tau_{i1} & .. & .. & \tau_{in} \\ .. & & & .. \\ .. & & & .. \\ \tau_{ni} & & & \tau_{nn} \end{matrix}}_{IOmatrix} \right)}_{A_{n,n}} \begin{pmatrix} D_i \\ .. \\ .. \\ Dn \end{pmatrix} \tag{15}$$

$$\begin{pmatrix} D_i \\ .. \\ .. \\ D_n \end{pmatrix} = \begin{pmatrix} d_i \\ .. \\ .. \\ d_n \end{pmatrix} + A_{n,n} \begin{pmatrix} D_i \\ .. \\ .. \\ Dn \end{pmatrix}$$

$$(I - A_{n,n}) \begin{pmatrix} D_i \\ .. \\ .. \\ Dn \end{pmatrix} = \begin{pmatrix} d_i \\ .. \\ .. \\ d_n \end{pmatrix}$$

So that:

$$\begin{pmatrix} D_i \\ .. \\ .. \\ Dn \end{pmatrix} = (I - A_{n,n})^{-1} \begin{pmatrix} d_i \\ .. \\ .. \\ d_n \end{pmatrix} \tag{16}$$

We multiply this by our passtrough 0.424662777 to obtain deflationary pressures for each industry, which are summarized in table 8:

industry	t1980_1985	t1985_1990	t1990_1995	t1995_2000	t2000_2005
AGRICULTURE.	-.0014448	-.0077379	-.0162075	-.0532541	-.0342304
BASIC METALS AND FABRICATED METAL	.001761	-.0268828	-.0420137	-.0856984	-.0599818
COMMUNITY SOCIAL SERVICES	.0058288	-.0248059	-.0403481	-.0928585	-.0591432
CONSTRUCTION	-.0006828	-.0107561	-.0208391	-.0669404	-.0503406
Chemicals and chemical	.0051105	-.0396391	-.071001	-.1673356	-.1191718
Coke. refined petroleum and nuclear fuel	.0010565	-.0207428	-.0345303	-.0885687	-.0526604
ELECTRICAL AND OPTICAL EQUIPMENT	.0151234	-.0497145	-.0789655	-.1299816	-.0852493
ELECTRICITY. GAS AND WATER SUPPLY	.0104017	-.0199855	-.0672421	-.1495134	-.1214258
FINANCIAL INTERMEDIATION	-.1137028	-.1681125	-.2274865	-.6141078	-.3118763
FOOD . BEVERAGES AND TOBACCO	.0018629	-.0210234	-.0313142	-.0771551	-.0558059
HOTELS AND RESTAURANTS	.0026822	-.015699	-.0228154	-.0603194	-.0358647
MACHINERY. NEC	.0046414	-.0407755	-.0646774	-.1288414	-.1089774
MANUFACTURING NEC; RECYCLING	.0014811	-.0366686	-.0554139	-.0999358	-.0659924
MINING AND QUARRYING	.0025574	-.0196864	-.0433528	-.139288	-.0694459
OTHER NON-METALLIC MINERAL	-.0290961	-.0429596	-.0522813	-.0974063	-.0747342
POST AND TELECOMMUNICATIONS	.2103041	.0033245	-.1414979	-.5477999	-.4479882
PULP. PAPER. PRINTING AND PUBLISHING	.0041606	-.0495904	-.0587716	-.1124032	-.0966937
BUSINESS ACTIVITIES	-.0016534	-.0708699	-.0748538	-.185213	-.0975098
Rubber and plastics	.0010627	-.0195773	-.0272203	-.0679724	-.0526164
TEXTILES. LEATHER AND FOOTWEAR	.0004671	-.0130799	-.0226252	-.0604583	-.0463699
TRANSPORT AND STORAGE	.0133855	-.0059847	-.036788	-.1580925	-.1462347
TRANSPORT EQUIPMENT	-.0124889	-.0379156	-.0429541	-.0786431	-.0569757
WHOLESALE AND RETAIL TRADE	-.001192	-.0576846	-.0746703	-.193224	-.1140978
WOOD AND OF WOOD AND CORK	-.0200373	-.0232127	-.0295379	-.0580827	-.0394092
_TOTAL INDUSTRIES	.0012451	-.0438671	-.0660024	-.175787	-.1098008

Table 8: total deflationary pressures from falling ICT prices per industry

A similar table can be found for the Netherlands in appendix I. As expected taking into account the impact of ICT on intermediary consumption magnifies the direct impact of ICT on inflation. Between 1995 and 2001 this difference is a non trivial 0.04. The sectors that benefited the most were « post and telecommunication » and « financial intermediation », whose prices decreased by respectively 0.55 and 0.61 percentage points.

Overall one could conclude from this table that ICT as an input surely has helped keeping inflation down as early as 1985, and especially after 1995. Nevertheless this effect, although non trivial, is to us unlikely to be the full story of ICT and inflation.

6.3 Limits and possible ways forward

Due to the broadness of the subject considered and the time constraint faced, our study contains a certain amount of flaws. We provide in this section a summary of these, some of which have already been mentioned as we were progressing,

We consider the main flaw of the paper to be that it may account insufficiently for industry differences. We have already discussed the issue of differences in markups which may affect the price levels and thus their growth of prices. Taxes are likely to have a similar effect. The fact that our dummy for country does not seem relevant is reassuring in this context, as we expect differences in taxation to be more country-specific than industry-specific. Nevertheless industry differences in taxation, and more generally sector specific policies such as subsidies in agriculture, may have polluted our results.

A bigger issue lies in the evolution of markups overtime, particularly stemming from differences in the evolution of demand between sectors. Our controls were meant to account for such an evolution and avoid an omitted variable bias, and some actually performed well such as the evolution of imports; however their inclusion was sometimes complicated by their costs in terms of observations. We have considered using a simultaneous equation method to proxy demand then plug it into our regression, but this was hard to implement within the time constraint.

There are nevertheless a few elements that lead us to believe that the problems met in capturing demand do not threaten our findings this much. One element comes from our relatively high level of aggregation. Indeed while difference in demand evolution may be very large for some particular products, these differences should be smoothed when we group them with other products. Another element comes from our findings themselves. The results of specification (2), which includes the log of imports, and (5), our preferred form, are not so different qualitatively and in terms of significance. Finally and most importantly, anecdotic evidence tells us that the industries that have experienced a rise in demand since 1980 tend to be the very ones which invested heavily in ICT (market services, actual IT production), with the notable exception of oil production. Therefore we believe that if there is an omitted variable bias that is likely to go against us.

One obvious issue when dealing with sectors is the level of aggregation. In our study the number of sectors is quite low, which was necessary considering the data we had. We have mentioned the positive effect of aggregation with respect to capturing industry differences. However the same smoothing property of aggregation plays against us for our ICT measures. For instance having to group retail trade with other less ICT intensive subcategories prevented the explicit inclusion of a sector that has invested heavily in ICT and experienced large gains in productivity. By grouping it we have diluted its effect and lowered the sample variation in explanatory variables. Thus although the effect on coefficients is uncertain, the impact of aggregation on the robustness of our results has in theory been negative.

We see two possible extensions to this work. One, which was initially what motivated this work, would be to relate productivity growth from ICT to trade patterns. Did industries which have experienced the most productivity gains export more? The answer to this question would require more countries in our analysis. One would also probably need to run panels on different countries for a given industry to have a clearer idea of who should be more competitive in a given market. Finally this would also require more complete data on trade, and particularly on services.

The second extension would be to run a similar regression on profits. Indeed in our model we have assumed that the rate of markup was zero, so that any productivity gain had to translate to prices. In theory, firms could also increase their markup leaving prices constant and pushing up profits. Our evidence seems to point out that the more you invest in ICT, the lower is your price. This would imply that the cost saving effect has been larger than the evolution of the markup, but not than the markup has not gone up. Studying profits would thus be interesting from a purely macroeconomic perspective as it would relate to the issue of the sharing of productivity gains; and in our context as it would help to assess the strength of the pro competitive effect of ICT mentioned in section 3.1.3. If the biggest ICT spenders have had larger profits than other industries, this would imply that this pro-competition effect has been limited, or at least equal amongst industries regardless of ICT spending. Appendix J provides a first step towards such an estimation, and discusses its shortcomings.

7 Conclusion

As this paper is a first attempt at capturing the disinflationary effect of ICT, we believe that the results obtained should foster future research. Long lagged ICT investment has the expected negative and significant impact on price evolution. The study is also relevant to the debate on the interpretation of TFP. Indeed the fact that ICT in itself has a negative function of prices but is negatively correlated to TFP, a priori, brings support to the argument that TFP is a biased estimation of technology advances. Our robustness tests also point in this direction.

One undisputable disinflationary pressure of ICT is its falling prices. Our estimation of such pressures gives an impact as high as -0.18 on average between 95 and 2000 for the US, using a fairly conservative measure of the pass-through from costs to prices. If we add our productivity effect, we estimate that the average deflationary pressure from ICT over this period has been of 0.24 points for a given growth rate. Although such an estimate should of course not be taken literally, as the variance of the coefficient on our productivity measure remains quite high, this does suggest that ICT has really been a great contributor to this period's pattern of high growth and low inflation.

In turn this implies that Greenspan's much criticized stance on monetary policy during this period may actually have been appropriate, or at least that the intuition behind it was correct. The paper also has fiscal policy implications, notably for European countries which have yet to feel the productivity gains from ICT. Investing more in ICT or fostering its adoption, for instance by increasing the number of IT graduates, could help them to experience a similar high growth and low inflation episode.

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Appendix A

Sectors in EUKLEMS and sector used

**BASIC METALS AND FABRICATED METAL	**POST AND TELECOMMUNICATIONS
CHEMICAL. RUBBER. PLASTICS AND FUEL	PRIVATE HOUSEHOLDS ...
**Chemicals and chemical	PUBLIC ADMIN... DEFENCE... SOCIAL SECURITY
**Coke. refined petroleum and nuclear fuel	**PULP. PAPER... PRINTING AND PUBLISHING
**COMMUNITY SOCIAL AND PERSONAL SERVICES	Real estate activities
**CONSTRUCTION	**REAL ESTATE... BUSINESS ACTIVITIES
EDUCATION	Renting of m&eq and other business activities
**ELECTRICAL AND OPTICAL EQUIPMENT	Retail trade. except of motor vehicles...
**ELECTRICITY. GAS AND WATER SUPPLY	**Rubber and plastics
EXTRA-TERRITORIAL ORGANIZATIONS ...	Sale. maintenance and repair of motor vehicles ...
FINANCE. INSURANCE... BUSINESS SERVICES	**TEXTILES... LEATHER AND FOOTWEAR
**FINANCIAL INTERMEDIATION	TOTAL INDUSTRIES
**FOOD . BEVERAGES AND TOBACCO	TOTAL MANUFACTURING
HEALTH AND SOCIAL WORK	**TRANSPORT AND STORAGE
**HOTELS AND RESTAURANTS	TRANSPORT STORAGE COMMUNICATION
**MACHINERY. NEC	TRANSPORT EQUIPMENT
**MANUFACTURING NEC; RECYCLING	**WHOLESALE AND RETAIL TRADE
**MINING AND QUARRYING	Wholesale trade and commission trade..
**OTHER COMMUNITY. SOCIAL..SERVICES	**WOOD AND OF WOOD AND CORK
**AGRICULTURE. ...	OTHER NON-METALLIC MINERAL

Table 9: EUKLEMS sectors, stars indicate those used in the study

Appendix B

Technical difficulties with productivity variables

ICT/VA: the choice of current values over volumes

EUKLEMS provides two types of variables: in volumes expressed as an indice with a base of 100 in 1995, and in current value as a share of total investment of per hour worked. One problem is that volumes, even normalized, are likely to reflect industrial differences in global investment, which are themselves driven by other factors. Our controls, particularly the evolution of non-ICT investment could partially adress this issue, but taking ICT investment as a share of an industry's value added (or total costs) does seem a more viable option. However using volume ratios can give us misleading values of the investment capacities of a sector by not accounting for the change in prices for each industry: for instance in the US the Coke and petroleum industry had an indice for value added in volume of 125.13141 and an actual value added of 19826.27 in 1987, while this values were respectively of 123.35625 and 75702.38 in 2006. This is why to express ICT investment as a share of investment capacity we have used current values.

INDIRECT INVESTMENT: classification-related problems and how they were tackled

Two separate sources were used for input-output matrices: WIOD database and STAN. The former provides annual data on 40 countries from 1995 to 2006 using NACE sectoral classification. Its list of 35 industries is a bit more detailed than EUKLEMS, with additional breakdown of the Transport sector and Textile and textiles products industries, but both are perfectly consistent. The latter covers the period 1980-1995 but the tables are only available every 5 years,. To estimate matrices for every year we thus use linear extrapolation for each sector j and product i. We note Ct the vector of ICT's share in total capital compensation. Since EUKLEMS provides this information for 30 sectors its format is (30 ;1)

As mentioned previously the use of STAN forces us to reagregate our data into 24 sectors by sometimes reporting variables in the more aggregated SIC rev2 format. Here, this means that in both of our sources, we sum each subsector's intermediary consumption and regroup them into their wider ensemble. Therefore our input-output matrices count for 24 columns. The link between both versions of SIC was done via rev3. In some cases the compatibility was blurred especially in some « catch-all » sectors such as « Professional goods » or « Other

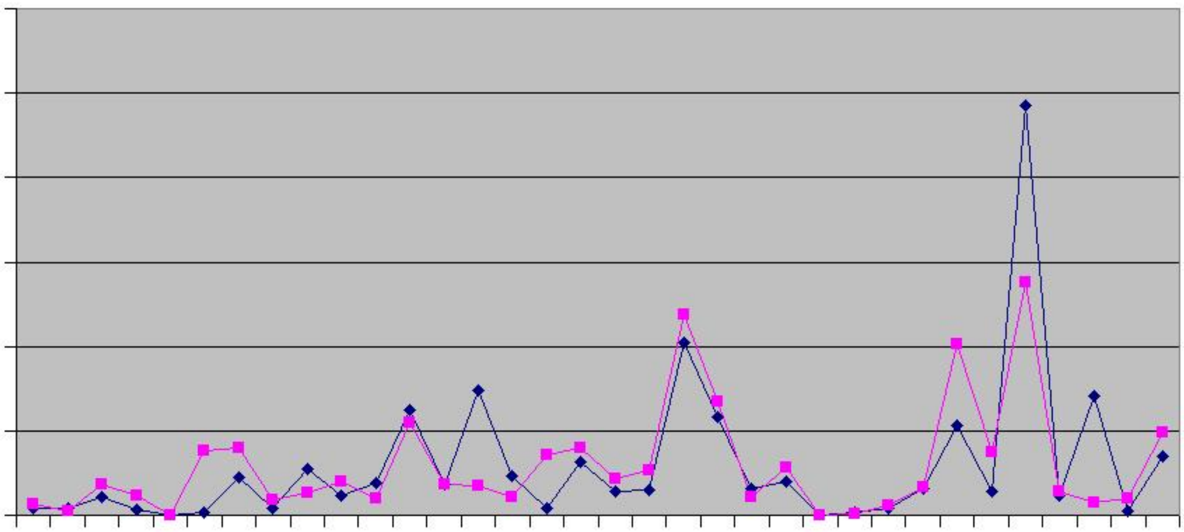

Figure 7: Comparison of technical coefficients “Electrical and Optical Equipment” and Manufacturing, Nec” 1995

manufacturing ». These were hard to correspond to their post 1995 counterparts, mainly « Electrical and Optical Equipment » and «Manufacturing, Nec; Recycling ». However the structures of inputs for these two sectors are very comparable, as highlighted in figure 7, Therefore any measurement error from imperfect matching is likely to have a negligible effect on our overall indicator.

The second step to obtain indirect investment is to multiply our vector of ICT spending by the input-output matrices. To do so, the matrix must have 30 rows. For WIOD matrices, this simply implies grouping the subcategories on transport and textile to fit the more aggregated sector in EUKLEMS. For STAN matrices, however, we must separate intermediary consumption into the more disaggregated EUKLEMS sectors. This was done by reproducing for each sector j its structure of intermediary consumption at its closest observed value, where t=1995. For instance in the « retail and wholesale trade » sector, which has quite distinct ICT spending profiles and weights in each industry's intermediary consumption, for example, the « Paper and prining » sector's inputs includes 20% on sale, 20% on retail trade, and 60% on wholesale in 1995; and that each of these subcategories spend respectively 100, 100, and 200 on ICT capital in 1990. If paper and printing's total purchases towards « retail and wholesale trade » are of 1000 in 90 then we estimate the detailed intermediary consumption to 200, 200, and 600 for each subsector respectively, and its embodied ICT capital to 150.

COMPLEMENTARY INVESTMENT: a small discrepancy

The detail on labour composition is available on EUKLEMS in the SIC rev3 classification. Somehow there are differences between data using SIC and data using NAICS in EUKLEMS. However these are minor , and the fact that we use ratios should reduce such incompatibilities even further.

Appendix C

The mathematical decomposition from section 4.3 implicitly assumes that α and 1-α are know exactly at every time t. In our case we only have these value every year, so we cannot know the structure of inputs for a given month. In other words we ignore the substitution that occurs within each year. This occurs accross our inputs, but also within them, for instance for any substitution of an intermediairy good for another. We can only partly account for this by taking the average of factors income share between t-1 and t, so as to get the average share of each factor during the year t-1. Overall though we believe this measurement error should be small. Figure 8 confirms this impression by plotting actual total cost and our mathematically expressed one for randomly selected industries.

We express total costs in the same format as our dependent variable: we express it as an indice and take its log. This way we will be able to study how an increase in 1% in costs translate into prices evolution.

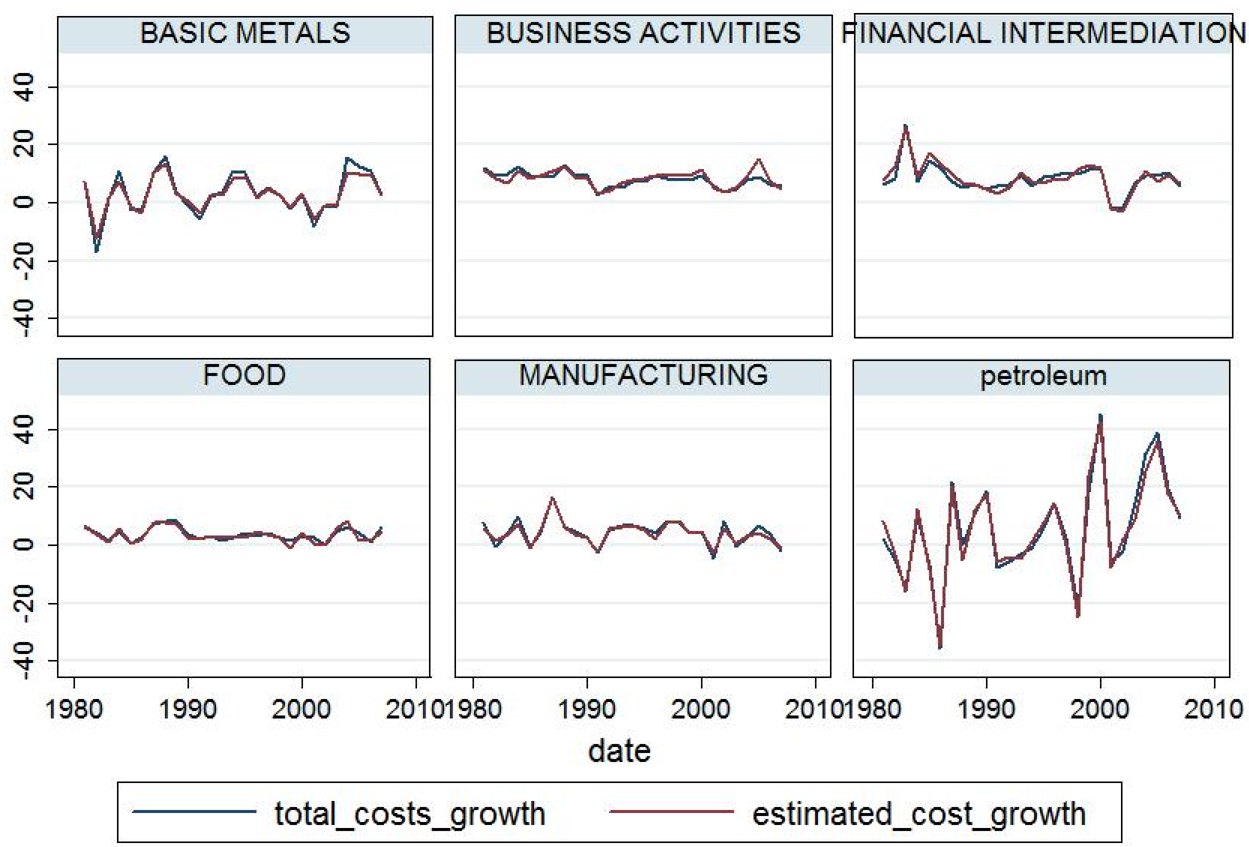

Figure 8: discrepancy between estimated cost and actual cost

Appendix D

Manipulations to controls

Controls from EUKLEMS did not cause any problems. For « STAN controls », let us first note that trade data is provided by the OECD in dollars, so that data for both countries are comparable. The problem of compatibility for these variables was also not as pronounced here when we constituted our indirect ICT measure. Indeed, while values were sometimes available only at larger level of aggregation, they were still ranked using the SIC rev3 classification. When data was only available for wider sectors, it was those sectors which had already been aggregated previously when we were constituting our indirect investment variable, which is logical since the input-output matrices were also taken from the OECD.

However, there were two cases in which the information for a sector was incomplete. The « TRANSPORT AND STORAGE AND COMMUNICATION » sector, which gathers all subsectors with ISIC codes starting by 60 to 64, was the most problematic. This sector is split into « transport and storage » (60t63) and « post and telecommunication » (64) in EUKLEMS. The OECD only provides data for the sub-subcategory « telecommunication » (6420) ; there is a part of but not all of « post and telecommunication », which is not reported. This subcategory, nonetheless, represents on average 80% of the overall spending of « TRANSPORT AND STORAGE AND COMMUNICATION » in the U.S, and thus at least 80% of « post and telecommunication ». The problem is then to estimate what part of the remaining 20% in R&D spending also comes from « post and telecommunication » (64), and what part comes from « transport and storage » (60t63). We decide to allocate it according to their respective level of output, in order not to waste the valuable information from « telecommunication », and keep our sample to 24 (48) sectors. In the second case, the subcategories reported represented 99% of the variation of their wider ensemble so we decided to simply disregard the difference by setting the sector's R&D expenditure equal to the sum of its components.

A second manipulation was applied to our trade data. Here we have missing values for all years in the the sectors « retail trade » and « hotels and restaurants», as well as some subsectors whose wider sector we are interested in. However this missing data is not innocuous : either their activity entails being near their clients or, in the case of R&D, is usually internal to a given firm (we have data on licensing). In other words, these sectors are « non-tradables ». We therefore change the missing values for these sectors to 0.

Appendix E

Autocorrelation-corrected results for direct estimation

Variable	m1	m2	m3	m4	m5	m6
total_costs	.28492615	.39413213	.58334018	.37377935	.54567502	.03751009
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ICT	-1.1607654	-1.4389845	-1.4461581	-.42619227	-.70230769	-.05786858
	0.0016	0.0000	0.0001	0.1389	0.0134	0.2006
indirect_ICT	-.25833772	-.25440496	-.26380042	.0494291	.02535188	.00933961
	0.3828	0.2281	0.0430	0.7507	0.6962	0.5364
complement_I	.00992244	.00251687	-.00724199	-.02070595	-.0377741	-.00034116
	0.6376	0.8291	0.6066	0.0688	0.0017	0.8468
country	.05105626	.04693048	.07170656	-.01067849	.00271719	-.00076481
	0.2808	0.2277	0.0214	0.7485	0.9176	0.7944
smallness	5.031e-06					
	0.0526					
total_	-4.440e-06					
	0.0558					
profit	.0497544	-.01008309	.066972	-.07173532	-.01112574	-.00129093
	0.3666	0.7987	0.0053	0.0259	0.4731	0.6085
RD	-.17816754	-.3136084	-.22681902			
	0.5156	0.2006	0.2541			
elasticity~e	-.00007454	-.00007877	-.00002961	-.00003572	-.00002856	-4.003e-06
	0.1842	0.1401	0.3207	0.4674	0.2549	0.8983
elasticity~d	-.0018003	-.00082046	-.00024351	-1.768e-06	5.003e-07	2.053e-07
	0.0855	0.2762	0.0984	0.6966	0.9275	0.9764
IMPORTS	.00966357	.00638114		.00239117		
	0.0534	0.1151		0.4704		
NETTRADE	-.00280986	-.00158772		.00246779		
	0.4617	0.6246		0.2848		
NONICT				-.09828578	.07632049	-.00115268
				0.1856	0.1624	0.8774
lag_price						.47427614
						0.0000
forward_pr~e						.47308734
						0.0000
_cons	3.218916	2.8047233	1.9840898	2.849333	2.137187	.07082863
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0824
N	78	144	501	267	1056	1008
r2_b	.73841936	.58386179	.46638777	.35038962	.48701569	.99894039

Appendix F

Regression introducing the lag of costs

Variable	m1	m2	m3	m4	m5	m6
total_costs	.21157879	.31696685	.74194383	.46367676	.67629518	.37318981
	0.1201	0.0014	0.0000	0.0000	0.0000	0.0000
lag_total_~s	.12548629	.102171	-.25262449	-.10257276	-.26366102	-.36233025
	0.3991	0.4113	0.0331	0.3508	0.0013	0.0000
ICT	-2.323793	-1.3602038	-1.8183635	-.17213629	-.59915998	-.07937529
	0.0008	0.0697	0.0818	0.4543	0.0741	0.0045
indirect_ICT	.11759289	-.25640886	-.1606721	.05704085	.0773906	-.02409351
	0.8023	0.4914	0.6662	0.7611	0.4173	0.0287
complement_I	-.00303017	-.00156096	.01409026	-.03277323	-.01311338	.00040587
	0.8474	0.9421	0.6271	0.0163	0.2286	0.6076
country	.09567756	.0381657	.04195508	-.00178214	-.00760635	.0015938
	0.0452	0.5179	0.2465	0.9522	0.5855	0.3628
smallness	.00001034					
	0.2203					
total_	-9.432e-06					
	0.2165					
profit	-.03765694	-.06292814	.07922989	-.12657079	.00110195	.00532624
	0.6478	0.2136	0.1100	0.0996	0.9635	0.0228
RD	-.2280805	-.29779104	-.89566651			
	0.1355	0.1741	0.0084			
elasticity~e	-.00016294	-.00005931	-.00012264	-.00041374	-.00017901	-.00001858
	0.3649	0.0956	0.0013	0.0000	0.1709	0.3477
elasticity~d	-.00062887	-.0006386	-.00136884	-2.433e-06	-.00001158	-3.304e-06
	0.6061	0.6211	0.0078	0.5003	0.0278	0.0377
IMPORTS	.011778	.01201416		.0055668		
	0.2503	0.0230		0.3602		
NETTRADE	-.00573564	-.00471573		.00203396		
	0.5483	0.3779		0.7862		
NONICT				-.16440985	.16190684	.00167631
				0.4070	0.0012	0.7204
lag_price						.69031751
						0.0000
forward_pr~e						.30936701
						0.0000
_cons	2.9712929	2.6290637	2.434571	2.849486	2.6695306	-.05014244
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0292
N	78	144	501	267	1056	1008
r2_b	.94843619	.488171	.54409536	.20177886	.65714453	.99607307

Appendix G

Regression with more weight on « older » investment

Variable	m1	m2	m3	m4	m5	m6
total_costs	.3311784	.40960467	.51659905	.36201975	.42794672	.02567746
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ICT	-1.8281738	-1.0764619	-1.5002073	-.32527657	-.47947767	-.03669855
	0.0000	0.0000	0.0000	0.1435	0.0012	0.2230
indirect_ICT	.06351179	-.32502185	-.16307946	.0583096	.09981288	.00549503
	0.8167	0.1153	0.1503	0.6695	0.0298	0.6617
complement_I	-.00133589	.00021504	.00980813	-.02139713	-.01537048	-.0000379
	0.8890	0.9818	0.3517	0.0149	0.0056	0.9743
country	.09297872	.04423888	.04687088	-.00455477	-.00287444	-.00060609
	0.0006	0.2568	0.1111	0.8794	0.8254	0.8013
smallness	.00001025					
	0.0120					
total_	-9.330e-06					
	0.0121					
profit	-.01783771	-.03652932	.07921889	-.11167026	-.01222522	-.00120445
	0.6832	0.3632	0.0008	0.0004	0.2146	0.5628
RD	-.13233101	-.15960245	-.89785746			
	0.3998	0.4736	0.0000			
elasticity~e	-.0001718	-.00007916	-.00010473	-.0004196	-.00016462	-4.222e-06
	0.2949	0.4643	0.2572	0.0065	0.0883	0.8896
elasticity~d	-.00034374	-.00054533	-.00146715	-1.591e-06	-.00001191	-2.777e-07
	0.9029	0.7003	0.0005	0.9096	0.5791	0.9672
IMPORTS	.01294238	.0108894		.00452676		
	0.0420	0.0295		0.3410		
NETTRADE	-.0078693	-.00538265		.00182633		
	0.2306	0.2889		0.6897		
NONICT				-.10889497	.11148324	-.00363463
				0.0531	0.0000	0.4610
lag_price						.48841635
						0.0000
forward_pr~e						.47830903
						0.0000
_cons	3.0110947	2.7063791	2.3140581	2.8703686	2.6107218	.03695656
	0.0000	0.0000	0.0000	0.0000	0.0000	0.2816
N	78	144	501	267	1056	1008
r2_b	.94921361	.51442117	.53220184	.28900603	.61170272	.99938937

Appendix H

First stage of specification (5) in IV regression

First-stage G2SLS regression

Number of obs =	1056
Wald chi(8) =	134
Prob > chi2 =	0.0000

log_TFP	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
log_total_~e	.0618712	.0074877	8.26	0.000	.0471956	.0765468
NONICT_VA_~s	.0308607	.0270375	1.14	0.254	-.0221318	.0838533
country	-.0165071	.011838	-1.39	0.163	-.0397091	.0066949
profit_OPT~L	-.0031789	.008121	-0.39	0.695	-.0190958	.012738
elasticity~t	.0000201	.0000613	0.33	0.743	-.0001001	.0001402
ICT_VA_5ye~s	.0359662	.1488872	0.24	0.809	-.2558474	.3277797
indirect_I~L	.0023708	.030702	0.08	0.938	-.0578041	.0625456
complement~s	.0096918	.0053092	1.83	0.068	-.000714	.0200975
_cons	4.306323	.0355973	120.97	0.000	4.236554	4.376093

Appendix I

ICT and profit

Variable	m1	m2	m3	m4	m5	m6
total_costs	1.0564649	1.128421	1.0918538	1.0959975	1.0550301	.0258594
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ICT	.3750139	.29472349	.1099996	-.72677237	.35160119	-.03576218
	0.4081	0.4130	0.7042	0.0118	0.1087	0.5203
indirect_ICT	-.09656653	.67631629	.21262185	-.04535441	.00484624	-.00650314
	0.7312	0.0003	0.0019	0.6333	0.8774	0.6469
complement_I	-.03757239	-.06552034	-.03164156	-.01341903	.0157602	.0002447
	0.0724	0.0007	0.0305	0.3803	0.0158	0.9108
country	3.149344	3.1058516	3.0518242	3.0637867	3.0221909	.00720535
	0.0000	0.0000	0.0000	0.0000	0.0000	0.2604
smallness	7.411e-06					
	0.0064					
total_	-6.528e-06					
	0.0072					
RD	.66306154	-.5449724	.23479856			
	0.0300	0.0308	0.1536			
elasticity~e	-.00009306	-.00011563	-.00002009	-.00010773	.00001207	.00002588
	0.1893	0.1406	0.6810	0.2310	0.8331	0.5713
elasticity~d	-.00246984	-.00113954	.00061041	7.761e-06	.00001099	2.743e-06
	0.0743	0.2782	0.0060	0.3408	0.3868	0.7871
IMPORTS	-.0107596	.00663146		.02009309		
	0.5515	0.5807		0.0384		
NETTRADE	-.00315377	.00121748		-.00442743		
	0.4770	0.7709		0.1424		
NONICT				-.20325037	-.40175517	-.01055843
				0.0070	0.0000	0.2417
lag_price						.49925191
						0.0000
forward_pr~e						.49859215
						0.0000
_cons	4.7639568	4.0715429	4.0559939	4.2649528	4.3013945	-.09537964
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003
N	78	144	501	267	1056	1008
r2_b	.85298951	.81716473	.75486154	.77877451	.7539738	.99999601